PROFITABLE SCIENCE IN INDUSTRY

FARNHAM, HALL, HOWE, KING

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TORONTO

PROFITABLE SCIENCE IN INDUSTRY

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New York
THE MACMILLAN COMPANY
1925

Set up and electrotyped.
Published January, 1925.

Printed in the United States of America by
J. J. LITTLE AND IVES COMPANY, NEW YORK

FOREWORD

The day in which an industry can be really successful without a close alliance with science is passing, if indeed it is not past, even as the chances for the self-made man uneducated to reach the top are diminishing. When there was an abundance of cheap raw materials, when labor took a pride in its work and freely gave service equal to its wage, and when incompletely developed transportation facilities restricted competition, the mistakes in manufacturing were not so serious. They could be offset by quantity production, just as costs were cut by the same method.

We have seen this condition completely change in our own generation. Many industries are called upon to use materials less satisfactory, as for example, an ore of poorer quality than that formerly available or much more difficult to work. Labor cost is such that in case a second grade article is produced, due to inferior raw materials or incomplete control of processes, the loss may be many times its worth. In many cases the material cost is so small a part of the total cost of the finished article that large fluctuations in the value of materials are so swallowed up by labor costs as to make no impression on the selling price. Manufacturers find themselves in world competition involving countries as well as individual concerns, and in several of these countries the value of science to industry is better known than in America.

Fortunately many American business men know from experience something of the potentialities of applied science. Notable examples are the electrical and chemical industries, with occasional conspicuous examples in mechanical engineering. The drafts made by such concerns upon the knowledge accumulated during the past two centuries threaten to exhaust the stock and arrest development in some lines until men can be developed to work upon the problems confronting them. Men thoroughly trained in the methods of research and well grounded in the natural sciences and related knowledge are the greatest need of the day.

The progressive manufacturer therefore has come to be interested in utilizing whatever scientific information exists. To do this he turns to the trained scientist. He soon finds need for additional knowledge to gain which he engages upon research. He soon finds need for additional trained men, to obtain whom he supports our educational institutions, in many of which by the fellowship system the facilities and experience of the staff may be made available to investigate fundamentals of importance to him, while at the same time the needed men are developed.

Industry is coming to realize that the work of the scientist is as vital to his permanent success as any of his activities and more necessary than many, and that science in industry represents not only a profitable investment but the only insurance possible against the most destructive of all agencies—ignorance.

S. W. Stratton, *President*
Massachusetts Institute of Technology

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CHAPTER I

INTRODUCTION

Dwight T. Farnham

The public at large is just beginning to realize its vital interest in the prosperity of industry. The war impressed the necessity of production and of conservation of resources upon almost every man, woman and child in each of the eighteen countries engaged. Output and the elimination of waste were impressed upon the citizens of the nations engaged on both sides in every possible way—by poster—by word of mouth—by every sort of propaganda.

Scientists and engineers in every country vied with each other in devising effective engines of war and efficient methods of production. Business secrets were pooled for the common good. Business executives served without pay. Industry was mobilized for victory and everyone was urged to united emulative effort by the public press.

After the war efficiency was urged in the interest of reconstruction—to replace the losses caused by nearly five years of destruction. Then the nations of the world

began to examine existing industrial systems. They began to experiment. Russia introduced communism on a large scale. Italy tried a similar experiment on a much smaller scale. England, France and the United States watched Russia and Italy, considered the matter and decided to get along under the old system, but not until the existing social and industrial system had been discussed by all classes.

In 1920 the world was hit by a general financial and industrial depression. Paper profits disappeared in a night. Dividends were passed. Factories were shut down. Managers and technical men were laid off. Workmen were out of a job. Grocers' and doctors' bills weren't paid. Contributions to the church and to charity fell off.

Everybody wanted to know what had happened to him, and why—so he could keep it from happening again. The man in the street began to study economics. The business cycle was nearly as widely discussed as prohibition and the world's series. Never in the history of the world had the general public of all countries been so well equipped by general education, by rapid means of intercommunication and by recent and forceful example to understand the fundamental laws governing the material prosperity of human society. The result was a gradual return of prosperity in every country not vitally injured by the war and the avoidance of the panic which threatened late in 1923, largely through sheer knowledge of economics on the part of the public in general.

How long the general public will remember the lesson of inflated prices, inflated labor values, the buyers' strike and of rehabilitation through the exercise of common sense and self-restraint upon the part of all parties to

industry remains to be seen. During the process, however, a much wider interest has been awakened in industry and the realization has become more general that the prosperity of the individual is in the long run dependent upon his understanding the industrial civilization of which he is a part and upon his exercising when necessary an intelligent influence upon that public opinion which has become such an increasingly great force with the democratization of the world.

The factors in industry which received most attention before the war were labor and capital. The world was full of theories about what labor could do if it owned its own tools. Russia tried the simple expedient of killing her capitalists and her technicians. In Italy the workmen seized the factories and after trying to run them for a few weeks discovered the value of technical knowledge, management, and credit and returned the plants to their former owners. Radicals in England were planning the unionization of foremen, technical and professional men, and managers when I talked with them after the Italian fiasco.

It is now pretty generally realized that the parties to industry are:—

1. The promoter—who discovers the economic need which justifies the creation of the business. He may be an inventor, a mechanical genius, a chemist, an electrical engineer or a plain business man, but he must have imagination and knowledge. He may be poor and without organization ability, but he must have the idea and the faith to make others believe in it.

2. The stockholders—who have sufficient belief in the enterprise to be willing to deny themselves the immediate pleasure of spending their money for the antici-

pated pleasure of having much more money to spend in the future. Sometimes stockholders are interested directly by the promoter and sometimes through the investment banker or other financial intermediary.

3. The directors—who are elected by the stockholders to protect their interests by doing what they can to insure continuous and large earnings—and dividends.

4. The management—which consists of the president, the vice presidents and the general managers, who are responsible to the directors for the conduct of the business in the most efficient manner possible—for the purpose of securing continuous and large earnings. The duties of the management are partly administrative (concerned with the determination of policy) and partly executive (concerned with the motivation of the human element of the organization for the purpose of successfully carrying out the policy agreed upon).

5. The staff—which consists of specialists of every variety, acting for the most part in administrative and research capacities although each may be chief executive over a considerable number of specialists. The staff advise the management as to financial, sales, technical and production problems of all sorts. They are generally lawyers, engineers, accountants, chemists, comptrollers, statisticians, personnel directors, geologists, doctors, publicists, and the like, and are specialists in their particular field.

6. The line—which comprises all the executives of the concern who are primarily responsible for getting things done—sales managers, factory managers, superintendents, foremen and supervisors of all sorts.

7. The rank and file—sometimes misnamed "labor" which consists of all those who do routine manual labor

necessary to sales and production whether clerical [1] or as part of processing material in the course of manufacture.

We have, then, seven parties to industry who are directly interested in the success of the enterprise with which they are connected. Indirectly, but no less vitally interested, are all the professions, trades, commercial enterprises, transportation companies, farmers, miners, and citizens of all sorts who produce, transport, buy and sell and earn a livelihood in the community. The material prosperity of these people has been wrapped up in the prosperity of industry since the steam engine enabled the industrial countries to support ten or a dozen times the population possible under an agricultural or pastoral régime.

The most successful business enterprises from the standpoint of earnings rest upon a monopoly of some sort. A patent is a seventeen-year monopoly granted the inventor for his hard work and ingenuity. If everyone could dig diamonds and oil in his back yard the Kimberly syndicates and the oil companies would cease to earn dividends or to attract inventors. Even the professional man of outstanding eminence—the lawyer or doctor who commands enormous fees because he can do something no one else is thought to be able to do—is a monopolist in a sense. Search or research is at the bottom of every monopoly or partial monopoly.

Next in strength is the business founded on strategic position—the only factory of its kind in the district—the store on the corner of two main thoroughfares—the

[1] The distinction between pounding an adding machine and operating a drop hammer is largely a social one based upon the clothes which the environment in each case permits.

warehouses built on the waterfront of a city which grew. Such businesses are less certain profit producers than those of the first class. They are much more dependent upon chance, upon efficient management and upon service rendered. The district attracts a competing and more efficiently managed factory, the storekeeper becomes careless and unpopular, the tide of population changes and the strategic type of business loses its position of advantage.

The third type of enterprise is that founded on service and popular appeal—like the hotel or department store existing under highly competing conditions. In this sort of business effective management, novel publicity and popularity are vital necessities if the enterprise is to continue to exist.

Countless industries have been founded upon monopolies, the patents have expired or have been circumvented, other mines or wells have been discovered or other processes have been invented and the business has gradually died. That is why such organizations as the General Electric and the American Telephone and Telegraph Company maintain research departments so organized and so staffed that the chance of a competitor outdistancing them in discovery is comparatively remote. In addition such concerns maintain a staff of the most eminent legal talent, so that the chance of their being driven from what virtually amounts to a monopoly is very remote. As long as reasonable common sense is exercised in management and the interests of the public are kept clearly to the fore, steady earnings and safety of investment are assured.

In the strategic type of business much more alert and effective management is necessary than in the type we

have just described if the enterprise is to maintain its position of advantage. The administrative function of management, which is responsible for securing the facts and so interpreting them that the most profitable policy can be determined upon a basis of facts, is more important than in the first case. Research is no less important, as there is always the chance of climbing a step nearer the monopoly type of business by the development of new processes or cheaper methods.

In the highly competitive type of business the maximum in management, technical knowledge and research are vital necessities. That is why the most successful department stores pay the merchandise managers of such highly temperamental departments as women's ready-to-wear more money than the presidents of some of our largest monopolies receive, and why hotel managers with an unusual talent for publicity or management are soon operating chains of hotels. The management of the business based on service must have all obtainable knowledge at its command and the best talent available in its organization if it is to earn satisfactory dividends in the face of continual cut-throat competition.

Research to insure the safety of invested capital, then, is essential in the first type of industry. Research to maintain strategic position is essential in the second class, and research to secure every advantage in the fight for survival is vital to the third class of industry.

Effective management is least necessary in the monopolistic type of business and becomes increasingly necessary as the danger of being supplanted or crushed increases.

Aside from the purely cold-blooded business aspect of the situation there is another view of the case which

should not be neglected. From the time of the entrance of the steam engine into industry the trend has been steadily toward the replacement of muscle power with machinery and brain power.

In America it has become almost impossible to induce the native-born or English-speaking citizen to perform manual labor. He will take a white-collar job as a clerk at comparatively low wages, but ask him to lay brick, plaster, or paint and you've got to pay him more than the average professional man earns. The only reason the country stood for the unrestricted immigration of less desirable races as long as it did was to permit work to be performed which the average American citizen was unwilling to do. The restriction of immigration has resulted in the stimulation of mechanical handling devices of all sorts. With the spread of general education it has been part of evolution to provide for the replacement of hand work with head work and to make the former manual laborer a foreman as it were, who in operating a single machine directs the work of the equivalent of twenty of his former selves.

All this has had a very marked effect upon the material prosperity of every citizen. Robinson Crusoe on his island had only what he produced. The isolated community of a hundred years ago produced most of what it had. The men tilled the soil and tended various domestic animals while the women preserved, cooked, spun, wove and made clothes. A suit of clothes had to last ten years and the possessions of the family were meagre in the extreme. Contrast the possessions of an agricultural or small industrial community of a hundred years ago with the modern workingman with his Ford, his movies, his foods and his stylish clothes. Research and management

have made possible the production of so much vaster quantity per capita that our material possessions have increased more than a hundred fold.

This evolution has been gradual, the results of research have matured as the common man has been educated to substitute head for hand work. As he has done so his material possessions have increased, his wants have been stimulated, and his scale of living both at home and at work have increased.

Compare the conveniences and luxuries of the manual laborer of today with those of a sixteenth century duke. For breakfast Bill Jones has fresh grapefruit from Florida, pork chops in just the right condition properly cooked over a gas range, fried potatoes, coffee from Brazil, white bread and buckwheat cakes with maple syrup. When he gets through he lights a cigarette. The duke had to get along with a piece of improperly fed cow, kept either too long or not long enough, raw and burnt in alternate spots from roasting before an open fire, some brown bread and a cup of mead. He had no coffee, no grapefruit, no potatoes, no white bread and no maple syrup. He had never heard of tobacco.

The duke lived in a cold draughty stone castle and never took a bath, while Bill lives in a steam heated apartment with a porcelain tub. Bill has electric lights and movies in the evening, the duke either got drunk by candle light or went to bed. If the duke wanted to go anywhere he went on a horse at about twelve miles an hour at considerable physical wear and tear. If it rained, he got wet. Bill has his choice of an electric car or subway, a steam train or an automobile, and in some cases can use an aeroplane. He travels from twenty-five to a couple of hundred miles an hour and does so with ease

and safety. Parallels of this sort might be drawn indefinitely. The contrast even fifty years ago is startling. Only the briefest study of living and working conditions in the time of our grandfathers shows the immense progress due to research. In New York I know a man, still in his prime, who less than forty years ago attempted a consolidation of *all the electrical concerns in the world*—and there were only ten of them.

In the successful industrial organization management based on opinion is rapidly being replaced by management based on facts. It has always been necessary for someone in each business to determine a general policy for the business and then to render decisions each day on matters which call for the creation of minor policies and for the reconciliation of current business with established policy.

Thirty-five or forty years ago industries were comparatively so small that the one man in charge was usually the principal stockholder and was very often responsible to no one as to the conduct of the business. Industry in general was much less complicated and business was much more local so that it was comparatively simple for the proprietor to compose his policy as he went along. He took what came to him and made his decisions as the necessity arose.

In the 90's the era of consolidations began. This was brought about by destructive competition, by the profitableness of promoting trusts and for certain economic reasons which may be outlined as follows:

Industrial consolidation, when wisely and honestly done—

1. Insures a lower cost of manufacture through the continuous quantity production of standardized articles.

2. Saves expense through consolidation of administrative, sales, advertising, insurance, etc., departments.

3. Saves transportation charges on raw material and finished product.

4. Provides for pooling of knowledge, methods and processes.

5. Makes mass purchase possible—with assurance of uniform quality and low cost of raw materials.

6. Makes maintenance of superior quality possible.

7. Reduces interest and depreciation on stores of raw material and semifinished and finished products.

8. Reduces amount of capital required per unit produced.

9. Increases ease of financing—securities are more liquid and more stable.

10. Permits use of research laboratories—and all that that implies.

11. Increases security of patents and trade marks.

12. Permits securing highest class of administrators and executives.

13. Permits retention of highest class of staff experts—lawyers, engineers, chemists, etc.

14. Makes comparative management possible together with most effective administrative methods.

As industries grew in size they embraced much wider territories. Problems of exchange and transportation arose. Finance became much more complicated. Men began to talk about the business cycle. Traffic managers were created. Advertising became one of our great industries. Market analysis was created. Economic and financial services like those of Harvard and Babson were considered indispensable. Great credit organizations and enormous banking institutions arose.

As a result of the increased size of industries it became no longer possible to decide matters of policy offhand from day to day as they were brought to the attention of the administrator. Decisions were too momentous. They involved too many millions. It took too long to gather the data.

It therefore became necessary to gather the facts *before* they were required. This was responsible for the creation of what is known as administrative control.[2] Administrative control in a large industry emanates from the statistical department which is part of the comptroller's department which is usually in charge of the treasurer or the vice president in charge of finance in the most modern type of organization.

In the more progressive concerns, such as the American Telephone and Telegraph Company, all the information likely to be required to run the business is continually available in chart form. The graphic chart has been generally accepted as the best means of showing at a glance the existing condition of any phase of a business as compared with conditions in the past. Isolated figures are less valuable without their context and abnormal conditions are lost in multiple columns of figures, all of which look more or less alike.

A complete modern installation of administrative control includes standards of performance as well as the actual results obtained during fixed periods. This means that a financial forecast and a budget system are tied in with the control charts. The procedure is roughly as follows:

[2] See series of articles in the Engineering Magazine (Industrial Management) for 1916 on "Scientific Administration" and in Administration, May, 1922, on "Industrial Administration" by Dwight T. Farnham.

1. A budget committee is organized. The economic reason for existence and the objectives of the business are analyzed and stated.

2. The balance sheet is analyzed and the part each department should play in the production of profits is determined.

3. Responsibility is fixed by tying departmental expense into the organization chart by means of account numbers.

4. Sales quotas are set by districts and a production program is drawn up.

5. Departmental expense is analyzed and predicted in the form of standards. Where practicable this should be carried to the point where standard rates for standard tasks are set for all workmen.

6. A financial forecast is drawn up. Standard income statement and balance sheet are prepared.

7. Actual results attained each month are compared with the standards set. Discrepancies are analyzed and steps taken to correct operating faults. Future standards are modified to meet changing conditions.

The result, where a budget system is properly installed, should be:—

1. Organized foresight instead of decision by guess.
2. Team play for a fixed objective.
3. Substitution of "responsibility for" for "authority over."
4. Systematic analysis and improvement of conditions in each department.
5. Reduced expense.
6. Increased effort to secure results.
7. Maximum earnings which economic conditions permit.

8. Greater individual satisfaction, increased understanding, and greater cooperation between the parties to industry—labor, management, stockholders.

When a business is operated on a basis of facts, actual results being regularly contrasted by means of graphs with the best prediction of the future which can be prepared from a careful and systematic study of all the facts obtainable, its chance of success is increased materially. Since the psychologists have been getting to the bottom of what is really responsible for a "hunch," there has been less decision as to important operating policies based on soothsaying and more based on facts. With such a system of administrative control as we have described, decisions as to policy are reached almost automatically. The continued prosperity of the business furthermore is much less at the mercy of some superpersonality who has been able after a fashion by sheer brain power to assimilate enough of the basic facts to manage somehow to keep the business going.

In the past many men's businesses have died with them. Other concerns have paid exorbitant salaries to men who were "shrewd" enough to keep in their own heads all they had learned at the expense of the business. There have been great numbers of mental breakdowns and business failures because men have tried to know everything and do everything personally in a big business by the same methods they had found successful in a little one.

Since the advent of administrative control the man responsible for shaping the policy of a great business can assimilate immediately—at a glance—facts which it would take him hours to dig out under the old system. He does not need to carry in his head great masses of

figures covering the past. He does not need to worry for fear he has overlooked something, as the slightest fluctuation from normal is noted immediately, investigated and corrective action taken. The use of the exception principle conserves his time for constructive and profitable thought.

Furthermore, since the charts are based upon figures which are prepared by the *whole organization* and are carefully corrected in conference by men whose judgment, each in his own particular line, is matured by years of direct contact with conditions in his own department, the decision as to policy is much more likely to be wise than where one overworked corporation president dashes through a mass of hastily prepared figures and renders snap judgment.

In addition, when once the various members of an organization have gone on record over their own signatures as to what they believe they can do in the way of sales, production costs and the like, the knowledge that the management will inevitably compare their estimate with their actual performance, acts as a stimulant which can only result in organized team play of a superior order.

Administrative control acts not only upon the line but upon the staff. The earnings of any business depend upon the spread between the unit sales price and the unit cost (sold) price multiplied by the volume of sales. The volume of sales depends upon cheapness of price, upon the quality of the product and upon the amount of sales effort. To maintain a spread between cost and sales price which will earn satisfactory dividends, the cost of manufacture must be reduced to a minimum. That means research in the factory by the staff. Improved

quality and the development of new products means research by the staff. Intelligent sales effort means research by the advertising staff and by the statistical staff.

In fact one of the best organized plants I ever encountered was an English plant in which there were three research departments—one under the sales department to develop new products of the sort the market would take and to analyze rejections, one in the stores department to analyze raw materials, and one under the factory superintendent, to cheapen manufacturing processes and to establish standards of output.

One German plant I visited analyzed all its raw materials before they were allowed to be unloaded from the cars. A Grand Rapids concern maintains a research bureau which investigates customers' problems and issues a monthly bulletin for their benefit. Most progressive concerns are continually analyzing their market in order to discover new fields and to develop more effective sales methods. They are also continually analyzing their rivals' products and marketing methods. Advertising has become so much a matter of continual psychological research that the largest advertising agency in America has one of the country's foremost psychologists on its staff.

The regular and systematic examination of the basic facts upon which the success of a business depends forces a company to probe into all sorts of matters whose importance would never be realized were it not for the existence of some type of administrative control such as we have cited.

The executive function of the management consists, as we have stated, in the motivation of the personnel to carry out the policy which the administrator has found to be necessary. The executive is a practical psychologist.

He knows how to inspire each member of the organization to exert his best effort. One man he praises, another he blames. He promises one man a raise if he will do better and threatens to fire another if his work doesn't improve. He does the same thing with his organization that the first-class teacher does with his class, applying just the treatment to each individual which his expert knowledge and experience with human nature has taught him is necessary in order to inspire each to do his best.

In the larger organizations the rank and file are under the supervision, in many of their relations, of a special member of the management, who is usually known as a personnel manager. The personnel manager is strictly a staff officer. The rank and file are usually under the supervision of the line officials who are responsible for the quantity and sometimes the quality of their work. Each officer is usually supreme in his own department but is restrained from autocratic action by the knowledge that trouble with one of his operatives will be investigated by the personnel department.

Under the direction of the personnel officer take place all sorts of research activities. Jobs are analyzed. Psychotechnical tests of employees and applicants are devised and carried out.[3] Educational systems, thrift systems, profit-sharing and housing systems and all sorts of welfare work must be investigated in the personnel department and the best of each applied to the industry for whose labor turnover and whose employee loyalty the personnel director is responsible.

As soon as the management of a modern industry begins to base its policy upon facts instead of upon opin-

[3] See Chapters XIII and XVI in America vs. Europe in Industry by Dwight T. Farnham, Ronald Press.

ion, it is inevitably led to research—research in finance, in sales, and in production. The officials who are responsible to the directors and to the stockholders for maximum and continuous earnings discover that they cannot proceed intelligently without a thorough examination of many things which had previously been taken for granted. As soon as such research work as we have described is begun, all sorts of conditions are discovered which demand immediate remedy. The result is increased earnings, increased safety of principal, and increased satisfaction upon the part of the entire organization.

CHAPTER II

SCIENTIFIC RESEARCH AND THE PROGRESS OF THE ELECTRICAL INDUSTRIES

R. W. King

The first year of the nineteenth century saw scientific laboratories and drawing rooms astir with talk regarding a startling discovery. With a little stack of metal disks, alternated with disks of cloth each moistened with acid, Volta had just succeeded in producing a continuous current of what was then that most mysterious agent, electricity. While the savants discussed, the laity asked questions, and so great was popular interest that Volta was called from Italy to the court of Napoleon I to show his experiments.

One hundred years passed during which the laboratories of science were productive to a degree never known before, and with the opening of the twentieth century, homes the world over we find being lighted, thousands of factories being operated, and millions of people transported daily by the agent which Volta discovered. And as we view these things today they scarcely excite our wonder. Beginning with the little "electric pile" of Volta, a century of intense scientific research has given the world great steam and hydroelectric generating plants whose currents are equivalent to the labor of hundreds of millions of human workers and these, being set to work

in countless types of auxiliary electrical apparatus, are bearing a large proportion of the burdens of the civilized world.

Recent data show that in October, 1922, central stations in the United States alone had a total rating of nearly 20,000,000 horsepower. The output of these stations is used for illumination purposes, for transmitting the 25,000,000,000 messages which are handled by our systems of electrical communication each year, for the refining of metals, for electroplating, for medical purposes, and for operating electric motors in factories, mines and elsewhere which are performing work conservatively estimated as equivalent to the manual labor of 200,000,000 men.

It would be difficult to find in the many fields of human endeavor better examples of the practical and economic value of research. It is no exaggeration to state that the entire electrical industry is the result of research applied to human needs. If anyone questions this let him, in thought, remove one discovery after another from our present day industrial structure and see how rapidly it crumbles away.

Let us take an example. One hundred years ago the Danish philosopher, Oersted, discovered that an electric current has the power of deflecting a nearby compass needle. A chance observation, and one which anybody could repeat today with a dry battery, a compass and a bit of wire. But it was the first time that any relation between electricity and magnetism, although often looked for, had been detected; and if this single fact were to be transferred back to the realm of the undiscovered, we would have to surrender, among other things, the electric motor, the telephone and telegraph, and the submarine

cable; cities would dwindle to the days of the horse car; factories would revert to the almost forgotten era of steam as motive power, and become again forests of whirling belts and shafting; and the world would again become dependent upon the post as the only means of communication.

Another illustration: Ninety years ago Michael Faraday discovered that a moving magnet can generate a current of electricity and that one current can generate another. He noticed that every time he moved a magnet through a coil of wire to which a galvanometer was connected there occurred a minute movement of the galvanometer needle. Today we need only look about us to see that Faraday's galvanometer needle has pointed the way to the harnessing of waterfalls, and the transformation of the energy of coal mines to operate electric railways, factories, and the network of telegraph and telephone lines which cover the continents. A new and more powerful means than the chemical battery of Volta had been found for generating electric currents.

THE RISE OF CENTRAL STATIONS

From the standpoint of money, the largest single factor in the electrical industry is the generation of current. The latest figures available indicate that the value of plant and equipment of central stations is well in excess of \$6,000,000,000. This big investment, however, does not preclude cheap power. Before the days of electric power, slave labor was considered cheap; today the electrical equivalent of a slave can be hired for a *year* for a sum that might keep a human worker for a week or two. Four dollars per year for the electric servant is the figure

obtained by dividing the total annual income of central stations by the man power equivalent of the electrical energy they generate.

Today there is scarcely a branch of the electrical industry or any industry which generation of power does not underlie. This is obvious in the case of lighting, transportation, electrochemistry and the driving of factory motors, but even a matter so far removed from the consideration of large amounts of power as the successful application of X-rays, is depending more and more upon just the right source of current to actuate the X-ray tube. Likewise, in the communication field large electrical generators are of fundamental importance. Although the current used to carry any individual telephone or telegraph message is extremely minute, the volume of messages is so great today that the use of chemical batteries in place of dynamos would be utterly impracticable.

The consumption of electric power has approximately doubled in the past five years and the prospects are that a similar rate of increase will hold for at least the immediate future. The resulting saving in labor is enormous, but economic saving of another sort is illustrated by the Grand Central Terminal area in New York City. Here a huge smoking uninhabitable pit, covering twenty-nine blocks, has been converted into one of the most attractive and desirable of New York's civic centers, simply by the electrification of the railroad tracks entering the terminal.

Great savings in coal are also effected, and we may confidently expect that research along many lines will develop still better means for converting the energy of coal into the energy of electric currents.

For example, it has been estimated that the complete electrification of the railroads of the country would save more than 100,000,000 tons of coal a year. Research has already made many electrifications practicable, and as time goes on we shall see the work completed.

In the matter of utilizing coal more economically the development of the steam turbine has been of great significance, but the reason for large turbines is found primarily in the demand for large amounts of electric power. In the turbine, a jet of steam is used to drive the rotating member directly without the intermediate cylinder and piston of the reciprocating engine, and a remarkable economy results. In twenty years the turbine has developed from an individual capacity of a few thousand horsepower to units ten times as large. The latest machines are capable of developing 80,000 horsepower or 500 times the power of the engines of the first central station which was opened by Edison only forty years ago.

Every step of the way, from the simple electrical experiments of the early nineteenth century to the 80,000 horsepower turbine with its direct-connected generator, has been paved by research. To give but the barest outline, there was first the discovery of current electricity by Volta in 1799. Then in 1820 Oersted observed that an electric current is always surrounded by a magnetic field. In 1825, utilizing this observation, Sturgeon constructed the first electromagnets. Shortly thereafter Joseph Henry began his justly famous researches in which he enunciated the fundamental principles underlying the design of electromagnets for various purposes. In 1831 Faraday observed the twitch of his galvanometer which, in a very literal sense, was destined to "electrify" the world.

It is related that a certain statesman once put to Faraday the question, "Of what use is your discovery?" to which Faraday replied, "Some day it may be developed so that you can tax it." With the value of the electric plants and equipment of the world bordering close onto twenty-five billion dollars, there is no lack of evidence that statesmen are busy demonstrating the truth of Faraday's prediction.

Faraday well appreciated the importance of his discovery, for to him belongs the credit of having built the first dynamo. This consisted simply of a disk of copper rotating between the poles of a horseshoe magnet and it could generate only a feeble current detectable by a sensitive galvanometer. But with it as a starting point there have since been developed the means of utilizing the energy of coal and waterfalls to generate, the world over, currents of electricity which in turn can convey tremendous energy across hundreds of miles of country over little copper wires, and drive the factories as well as carry the thoughts of the nation.

The list of scientists and engineers who followed Faraday in the perfecting of dynamoelectric machinery is much too long to give in full. The early generators employed permanent field magnets. These were later changed to electromagnets, after which a portion of the current of the generator itself was led through the field winding to increase the output. Then came the shuttle-wound armature of Siemens which recognized the importance of properly designing the magnetic circuit of the generator. In connection with magnetic circuits the theoretical work of the German physicists, Gauss and Weber, and the American physicist, Rowland, are of pri-

mary importance. Through their labors, and those of Hopkinson, it became possible to calculate the behavior of the magnetic circuit almost as readily as one can calculate the behavior of an electric circuit on the basis of Ohm's law. There now came in rapid succession the Gramme armature, the drum armature, and the multipolar machine, and more recently the use of alternating currents with the development of transformers, synchronous and induction motors, and huge alternators.

Power is now being transmitted for a distance of about 250 miles from Niagara Falls, and in California the longest transmission line reaches over 400 miles and operates at 150,000 volts. After the invention of the steam engine, but before the advent of the dynamo, power had to be applied where it was generated; that is, at the point where the prime mover was located. Water power could be used only to a limited extent because it was necessary to locate the mill or factory within a very short distance of the water power site. The direct current dynamo did little to alter this situation, although before long science will doubtless find a way to operate direct current systems at high voltages, it being uneconomical to transmit over long distances anything but high voltages.

About 1890 the workers of clearest vision in the electrical field began to realize the feasibility of alternating current machinery. The behavior of alternating currents is not so simple as that of direct currents, and indeed, to the average electrical engineer of thirty years ago, the phenomena of alternating currents seemed to present such a complex of intangible mathematics and untried ideas that he was not hopeful of the time ever

coming when the alternating current would be anything more than a scientific curiosity. But the time has come, and it was a matter of but a few years when a new generation of electrical engineers sprang up who were well versed in the sciences of physics and mathematics, and to this new generation of engineers belongs the credit of the great strides which the electrical industry has taken since 1890.

The first alternating current transmission line operated at about 2000 volts. Increases in transmission voltage have come steadily; a curve would show an increase of about 7000 volts per year on the average. Somewhat before 1900, 44,000 volt lines were in service; by 1912, the potential had risen to 150,000, and at the present time 220,000 volt lines are about ready to go into operation. And for all that we can tell, this is only the beginning. Researches are actively in progress for the purpose of making higher voltages practicable and any year may see the inauguration of a 500,000 or even a million volt transmission line, although it seems probable that such high voltages as these will necessarily involve the use of direct currents.

There is some talk of distributing power by radio but it is not possible to take this scheme seriously at the present time. Until some means is discovered for regaining from the ether all the power that might be imparted to it in the form of radio waves, and until it can be made impossible for those not paying for power to obtain it as readily as those who are paying, the scheme would seem to be little better than an absurdity. To accomplish these ends would require principles as yet undiscovered.

The striving for higher voltages has a sound economic

motive behind it. The higher the voltage at which currents can be transmitted, the greater the distance or the smaller the amount of copper necessary to transmit them with a given loss. For reasons which are obvious, our principal sources of water power are, in general, far removed from our industrial centers, and therefore the higher the voltage which can be handled on a commercial basis the more water power we can use economically.

There is another advantage in long distance transmission lines. By interconnecting the industrial centers of a wide territory, peak loads can, as it were, be sandwiched with one another, thus meeting all the power requirements of the territory with a smaller plant investment. This is an important point since, with all its marvelous convenience, electric energy cannot be readily stored in large amounts. To be sure, the storage battery is useful for light duty such as the operation of electric vehicles and the equalizing of small loads; but as a means of storing the energy of a waterfall it would be quite out of the question. By the building of long transmission lines, important centers can be supplied both from a region where water power is abundant and from a region where coal is abundant, the water power being used during such seasons as it is available with the coal as an alternative.

ELECTRIC POWER AND THE WORKINGMAN

Before leaving the subject of electric power another matter seems worthy of mention. Consider an average factory employing, say 1000 workmen, in which the machinery is driven electrically. The power consumed

in driving is perhaps equivalent to the labor of 20,000 men who, by virtue of a distant steam or hydroelectric plant, appear on the payroll of the factory only to the very small extent of perhaps $10 or so per man per year. The 1000 workmen actually employed are then virtually directing the labors of 20,000 others. Each of these 1000 workmen is serving in a foreman's capacity, directing the labors of twenty others. He is therefore receiving not only a foreman's wages, but he is also profiting by the cheap hire of the twenty electrical workmen whose efforts he is in effect directing.

Success in one line of research always opens up possibilities and also problems, in other lines. We read much these days concerning the mechanization of industry and the narrowing of the workman's duty to the point where it may be nothing more than supplementing the monotonous operation of a machine. It is only too true that division of labor has meant, to the great bulk of factory workers, jobs of narrow routine many of which consist of a single operation repeated thousands of times a day. and at the base of this division of labor lies the utilization of natural sources of power. If this were the whole picture, the increasing use of electricity in factories might well be considered of doubtful value. But cheap industrial power means more than this. It has already meant higher wages and shorter hours. With eight hours' labor the workman has eight hours to himself, and with six hours' labor, which science may make possible in the not distant future, he will have ten hours to himself. Here is a period of leisure nearly twice the working period, and it may readily be that the opportunities for self-development which are potential in it can more than counteract the supposedly harmful effects of the special-

ized job. Until a thorough attempt has been made to instruct the workman in the proper ways to employ his leisure, it would seem ill-advised to condemn the present mechanical and electrical age because of the narrowing which has taken place in the average industrial job. Here is a large field for research. It presents problems which no one ought to neglect who believes that our industrial age marks a step forward in the progress of civilization. Least of all can the industries themselves neglect it. It may well be that those industries with long records of successful research behind them will be among the first to attack seriously these problems the urgency of which is steadily increasing.

In forty years the electrical industry has sprung from a mere nothing, speaking from an investment point of view, to a total book cost of upwards of $25,000,000,000 and a generating capacity of 20,000,000 horsepower, nor has its growth stopped. It is frequently said that we are now living in an electrical age. Probably it would be more correct to say that we are approaching an electrical age. Only 55 per cent of the manufacturing establishments and mines in the United States are operated by electricity, and only 38 per cent of our people are living in electrically lighted homes. It is estimated that there are about two-thirds as many farms in this country today as there are wired residences, but less than 10 per cent of these farms are electrically lighted and the percentage which uses electrical energy as a substitute for the labor of human beings and animals is of course even less.

Hence there seems to lie ahead an opportunity for electrical science to bestow even greater benefits than those which it has already yielded. But many problems, scientific, technical and commercial are involved. Stein-

metz a few years ago calculated that we are using coal at a rate equal to the total water power of the entire country assuming every creek and stream and river to be harnessed to the utmost with water wheels. "This," he states, "is probably the strongest argument for efforts (research) to increase the efficiency of our means of using coal." At the same time our use of water power will increase as improved electric and hydroturbine machinery and transmission lines are found. One-third of the electric power now produced is generated by waterfalls and we have tapped but a small fraction of the hydraulic power available. There is finally the vast energy of the sun's light which is reaching us at a rate hundreds of times as great as the world's present power requirements. Coal and water power both represent solar energy transformed to a readily usable character, but the fraction of it thus transformed is well nigh infinitesimal. Harnessing the sun may be one of the great problems and research victories of the future. It has been well said that "the people of a coming day will look back upon our knowledge of the forces of nature as we now look back on that of the North American Indian who, cold and shivering, was ignorant of the coal at his feet with its stores of warmth and power."

THE TELEPHONE

There is perhaps no better illustration of research as an industry builder and servant of man than that supplied by the telephone. Here is an industry, almost every advance of which has been the direct result of applying scientific discovery, and its growth has been phenomenal.

Forty-seven years ago there was one telephone in the world, the instrument which Bell invented. Today there is, in the United States, one telephone for every eight persons.

Forty-seven years ago there were two telephone employees, Bell and his assistant; today there are 300,000.

Forty-seven years ago the world's entire telephone plant could have been held in one man's hand. Today in this country alone there are, among other items, 15,000,000 instruments, upwards of 21,000 central offices, and 25,000,000 miles of wire, the whole telephone plant showing a book cost of about $2,000,000,000.

Without the telephone the modern skyscraper would be more of an encumbrance than an aid to business. The telephone is as indispensable to the farmer as to the business man. It not only aids the farmer in his work but, like the automobile, helps to remove him from his isolation. It is estimated that one of every two American farmers possesses a telephone.

Last year the American telephone system carried 18,000,000,000 communications, or one message every day for every man, woman and child in the country, remembering that each message involves two persons. The total distance covered by these 18,000,000,000 messages was over 45,000,000,000 miles. Assuming that equally satisfactory results could be obtained were these messages to be carried by separate messengers, it is interesting to estimate the physical magnitude of the task involved. Assuming that each messenger works 9 hours a day and averages 10 miles per hour, it would require 6,000,000 messengers and at a conservative estimate would cost $10,000,000,000 to handle this business which the telephone handles at a cost of $500,000,000

and with 300,000 employees. Here, again, electricity is an efficient servant of the public.

Among the important features of the modern telephone plant which can be traced directly to science is the telephone repeater, which makes conversation over long distances possible and which has permitted the use, in many cases, of line wires of copper weighing 82 pounds to the mile as against 870-pound wires formerly used. Another instance is the lead-covered cable which is proof against storms and which holds within a sheath scarcely larger than a man's wrist as many wires as could be strung on forty large open wire pole lines. There are also "carrier current" telephony and telegraphy, making possible the simultaneous transmission of four telephone messages or ten or more telegraph messages on a single pair of wires. By applying the principle of the carrier telegraph to the conductors within a cable and making use of the multiplex printing telegraph which has recently been perfected, a single cable can, at a very conservative estimate, carry 48,000 telegraph messages simultaneously. The capacity of the wire system has therefore become practically unlimited.

To illustrate more clearly the practical value of research, several developments in the telephone field will be considered in some detail.

Take first the lead-covered cable. In earlier days telephone wires (and telegraph also) were strung separately and overhead. Forty years ago the Pearl Street central office in Boston accommodated about 1200 lines. If still visible today, that enormous structure, with its chaotic arrangement of wires coming in from all directions, would look far more like the head of some mythological creature than a part of a modern electrical

system. While the telephone was yet in its infancy, it became apparent that means must be found for placing circuits underground, at least so far as congested areas in cities were concerned. The particular roof structure just cited was carried away by a heavy blizzard in the winter of 1881, throwing its 1200 circuits out of service.

Now, those 1200 circuits could be carried in a single cable less than three inches in diameter. As to another practical significance of the cable, there are, under the corner of Broadway and Franklin Street, New York City, more than 35 cables, each containing on an average about 700 telephone circuits, making a total of over 47,000 wires under this single thoroughfare. This vast number of wires, if placed upon a single overhead line, would require poles two miles high or, if the poles were only as high as the Woolworth tower, Broadway would be roofed in by 12 gigantic lines and a veritable canopy of copper.

Into cable development have gone researches in metallurgy and in paper making, and an intimate knowledge of the behavior of high frequency alternating currents. In the first cables, the wires were insulated by rubber or some other moisture-proof compound. It was only several years later (1890) that the first paper insulated cable was constructed. This contained 50 pairs of wires. It proved so far superior to the previous cables that development was concentrated upon it. In 1892, cables were being laid which contained 100 pairs of wires, in 1900 they contained 400 pairs and in 1912 they contained 900 pairs. Two years later a 1200 pair cable was successfully developed, and more recently this has been extended to 1500 pairs, that is, 3000 wires. It should be understood that this increase in cable capacity has

not involved the use of a larger sheath. It has simply meant the packing of wires more closely together with a resulting saving in space which is extremely important when cables are to be placed in ducts underground. It is estimated that the development of these fine wire cables has yielded a saving, in the Bell system alone, of nearly $100,000,000.

In this system, over 15,000,000 miles of the 26,000,000 miles of wire are placed in underground cables, the cost of this invisible portion of the plant being more than $300,000,000.

It would be tedious to mention all of the incidental savings which applied scientific research has yielded in the case of telephony. The few that follow are taken from records of the Bell System because these were most available. Originally the lead of cable sheath was given a 3 per cent admixture of tin to impart the necessary mechanical properties to it. About twelve years ago the price of tin rose and the quantity required for new cable construction became so large that a substitute was felt to be imperative. Investigation resulted in a new sheath using 1 per cent of antimony. In ten years this new formula has resulted in a saving of close to $6,000,000. Another important metallurgical result gave an improved contact metal for the millions of relays and little switches which are needed in the telephone plant. Since 1916, the saving accruing from this new contact metal is over $13,000,000.

Two results of a strictly electrical character which proved extremely profitable have been the development of the phantom circuit and the perfection of the so-called loading coil. A simple circuit, of course, consists of two line wires, and two circuits consist of two pairs of line

wires. By phantoming, it is possible to superimpose a third circuit upon these two pairs using each pair as though it were a single line wire. The phantoming principle is particularly applicable to long circuits where the cost of additional copper wire would be an important item. At the present time there are about 400,000 miles of phantom circuit in the Bell System. The cost of obtaining these was about $9,000,000 and the cost of obtaining the same circuits by stringing new wire would have been about $90,000,000, leaving a saving of over $80,000,000. While the theory of phantom circuits is not at all abstruse, the difficulties encountered in manufacturing the equipment needed to put the theory into operation proved very formidable, and involved the application of research methods to a practical problem.

The effect of loading coils when installed in telephone circuits is to reduce the attenuation suffered by the voice currents as they travel. If in building our telephone plant the loading coil had not been available, and, in order to deliver over the long lines and cable circuits telephone currents of the magnitude required by the receiver, it had been necessary to resort to larger copper wires, these would have involved an additional expenditure of practically $100,000,000.

DEVELOPMENTS PRODUCED ON ORDER

By the year 1911 the American Telephone and Telegraph Company, in collaboration with the Western Electric Company, had built up a very successful research organization. Many difficult problems had been solved satisfactorily and subsequent events indicate that the directors and officials of the Bell System placed a

by no means unmerited confidence in their research staff. It was about 1912 that public announcement of the scheduling of the Panama-Pacific Exposition for 1915 was made. Following this announcement, an order was issued within the Bell Telephone organization to the effect that when the Exposition opened there should be a successful telephone circuit in operation between New York and the Pacific Coast. The order was obeyed. Opening of transcontinental telephone service was announced January 1, 1915; the opening of the exposition occurred on February 20.

Just what was the problem which arose from the issuing of this order? Long distance connections were by no means unknown at that time. Circuits between New York and Chicago were in common use and it was possible to talk from New York as far west as Omaha and even Denver under the most favorable conditions. But farther than this it was impossible to go. The copper wires running between these cities were the largest that it was practicable to string. Especially powerful transmitters and sensitive receivers had been suggested, but these could not constitute a solution of the problem because it would not be feasible to use one kind of telephone instrument when talking to various parts of New York City and another type of instrument when talking to the Pacific Coast.

It was therefore apparent that some relaying or amplifying device must be found which could be inserted at intervals along the long distance circuit automatically to restore the enfeebled voice currents to something like their original value. Investigations which were started at once disclosed that it might be possible to attain the desired end could sufficient progress be made along any

one of three different lines. One of these was to utilize the amplifying property of the carbon microphone; another was to employ the negative resistance characteristic of the mercury vapor arc; the third was based upon bringing under control the then erratic properties of the three electrode vacuum tube.

Much time was spent in an effort to bring the carbon microphone as applied in the so-called mechanical repeater to the required degree of stability and reliability. Great strides were made in this direction and long distance circuits were successfully operated for short periods of time, but in the final analysis the mechanical repeater had to bow before the superior qualifications of the vacuum tube. The mercury vapor arc did not prove as promising upon thorough investigation as either the mechanical repeater or the tube.

At the present time there are more than 3000 vacuum tube repeaters in operation in the Bell System. To render their service by other means would, it is estimated, have involved the additional expenditure of $95,000,000 during the past seven years and the annual charges alone on this additional plant would be over $12,000,000. To carry the voice across the continent twelve repeaters spaced about 300 miles apart are used, and when two persons converse over the transcontinental line they have set aside for their exclusive use about three-fourths of a million dollars' worth of equipment.

RELATIONS BETWEEN POWER DEVELOPMENT AND TELEPHONE DEVELOPMENT

Every growing thing possesses an environment. The larger it grows the more it is subject to reaction from its

environment. The business of telephony and the business of electric power distribution have both grown tremendously in the last few decades. Since the wires of each have necessarily been strung close together, along highways and elsewhere, it is natural that interference, purely electrical, should have arisen. When the electric trolley was introduced, it presented a very serious problem because the noise it caused in nearby telephone circuits made talking difficult and, in many cases, impossible. Also trolley currents had an annoying way of operating the central office switchboard signals and causing currents to flow through the ground to the lead telephone cables, corroding them away by electrolysis. However, by the continuous efforts of the engineers concerned, a practical solution of the electrolysis trouble was found and systems of transposition were discovered which have almost entirely eliminated interference between power circuits and telephone circuits. But the study of the problem of high tension circuits is an ever-present one, because what was high tension at the beginning is now very low tension. At first a potential of two thousand volts was considered to be high; now plans are being completed for lines carrying 220,000 volts.

The interference problems here involved are so important that it has been said, with considerable truth, that if high voltage circuits had been developed and put in use before the telephone was invented, the results obtained from the early telephone lines would have been so utterly impracticable that it is hard to think of anyone being rash enough to regard the telephone as having any commercial value.

SUBMARINE CABLE

From another field of electrical communication come two illustrations of the value of extensive scientific knowledge and of scientific research which are so clear-cut as to be almost unique. The laying of the first submarine cable created an entirely new electrical problem. Never before had the electrical profession been confronted with the question of getting a signal current to flow through a 3000 mile length of cable of high electrostatic capacity. The first corps of engineers employed attempted to get signals through the cable in a manner much similar to that already employed on land telegraph circuits. The effort not only ended in complete failure but also placed the cable itself in serious jeopardy. The work was then turned over to one of the leading physicists of the day, Sir William Thomson, later Lord Kelvin. Based upon a mathematical analysis of the transmission characteristics of the cable, Kelvin designed the extremely sensitive syphon recorder as a receiving element. Success was immediate, and even today the technique of cable operation differs but little from that devised by Kelvin nearly 60 years ago.

At the present moment we are, however, on the threshold of another great advance in submarine cable art. There has recently been developed by the research engineers of the Bell System a magnetic alloy of most remarkable properties. Among other things, this alloy will make possible the continuous "loading" of a cable with the result, according to tests thus far carried out, that a transatlantic cable of the new type will have four times as great a message-carrying capacity as the cables now in use.

These two advances in the submarine cable art far transcend any other individual advances in its history, and each is a striking illustration of the practical value of research.

RADIO COMMUNICATION

The heading of this section might, with justice, read "From Higher Mathematics to Vaudeville." Fifty-five years ago when the wireless telephone and telegraph first entered the world, they were wrapped obscurely in a few very involved mathematical formulas put forth by the English physicist Maxwell. Today, radio broadcasting is carrying the latest musical hits and the leading sporting events to millions of people all over the country.

In its early mathematical form, it is natural that radio should have evoked no widespread interest. Even Maxwell's assertion that the ether of space transmits peculiar electric waves—indeed, that the visible light of the sun and our artificial lamps are just such waves—attracted little attention.

Twenty years later wireless communication entered the realm of speculation when Hertz startled the scientific world by demonstrating the truth of Maxwell's prophecy that the ether will transmit electric waves, thereby establishing the latter's position as one of the leading theoretical physicists of all time. A decade later the first actual wireless telegraph emerged, very largely as a result of the efforts of Marconi. Some 25 years have passed since the first successful transmission of a message without wires, and the art has received improvements from the hands of many workers, so that today radio stands as a very successful means of communication with ships and

other moving stations such as aircraft, across the oceans, and to large groups of people as in broadcasting.

It was not the lot of the radio telephone to undergo as early development as the radio telegraph. The latter has long been familiar to everyone traveling on the seas, but the radio telephone has become only recently a thing of interest. To be sure, the wireless telephone was tried successfully in 1915 for transatlantic communication, and within the past two years has been demonstrated as a means of talking between a ship at sea and any telephone station on land but these demonstrations have been in the nature of laboratory tests. The war saw radio telephony used as a means of speaking from the ground to the pilots of flying airplanes, and radio in all its forms is now held in high esteem as a means of military and naval communication. Moreover, the development of radio for the automatic guiding of airplanes, torpedoes, etc., promises to have at least a spectacular and perhaps a very important future.

In spite of its rapid application to broadcasting and other lines, radio communication has not yet reached its ultimate stages of development. It is true that the capacity of the ether for radio messages is limited, so that even today interference between messages is an all-too-common occurrence, and with broadcasting, military and naval uses, radio compasses, ship-to-shore and transatlantic telegraphy, there are now not many wave length ranges of the ether unused. However, the application of radio to one of its most important fields is still a thing of the future. Today you can lift the receiver of your telephone and talk with any city of the land, though it may be 3000 miles away. But tomorrow, even the barriers of the oceans will have been removed, and

the resident of Chicago or Kansas City will be able to obtain a telephone connection to London or Paris or Tokio, as well as to New York or San Francisco. The scientific and engineering problems involved in transoceanic radio telephony have already been solved and there is needed only the clearing away of commercial problems to make it a reality. The telephone, through its power to transmit the human voice, is today of vast service to mankind, but who can estimate how much greater that service will be when even the great water barriers of the earth shall have been spanned, and citizens of the New World and the Old World, and of the Occident and the Orient, talk daily with each other?

CHAPTER III

ILLUMINATION BY ELECTRICITY

R. W. King

The possibility of electric lighting sprang into existence a century and a quarter ago when Sir Humphry Davy, making use of a large chemical battery developed from the newly discovered Voltaic pile, for the first time produced the electric arc. This was long before the days of dynamos. Davy also demonstrated the ability of his battery current to heat a platinum wire to incandescence, thus giving off an intense light. It was as far back as 1841 that an American, W. J. Starr, carried out much experimental work on an incandescent lamp consisting of an intensely heated carbon conductor in an evacuated glass bulb. Unfortunately, these early attempts at electrical illumination were doomed to failure; the day of engine or water driven generators was still far off.

With the advent of such generators, lamp research again became active. The problems of a successful arc lamp were much more readily solved than those of the incandescent lamp. As it developed, the production of a practical incandescent lamp involved chemical researches primarily. The first commercially successful incandescent lamps were of the work of Edison and Swan, who, independently between 1878 and 1880, produced satisfactory carbon filaments. Edison carbonized fibers of bamboo, while Swan developed a parchmentized cotton

thread and eventually the squirted thread of cellulose which was destined to become the universal process. An improved filament produced by the process of "flashing" in an atmosphere of hydrocarbon gas and later the production of the "metallized" carbon filament, brought the efficiency of the lamp to approximately 0.3 candle per watt. Meantime work was begun on metal filaments, and about 1902 tantalum lamps were produced with an efficiency of about 0.45 candle per watt.

Almost immediately the highly refractory properties of tungsten filaments were appreciated and it became obvious that the tungsten filament lamp would be the lamp of the future. The first tungsten filaments were made by squirting threads of tungsten powder, held together by a binder. In 1906, drawn tungsten wire was produced in the laboratories of the General Electric Company. Use of such wire is now almost universal and the incandescent lamp appears, for the time being, to have settled down to a form which yields an efficiency of from 0.6 to 0.7 candle per watt.

This is true so far as the small sizes are concerned. The chief limiting factor in the efficiency of the tungsten filament is not the melting point of tungsten, but the temperature at which the metal tends to disintegrate by volatilization. It was found that the filaments would burn for short periods at temperatures sufficiently high to yield the very large efficiency of about 3 candles per watt, and if volatilization could be prevented it should be possible to obtain this efficiency in practice. In an effort to overcome the serious effects of volatilization the laboratory of the General Electric Company developed the gas-filled lamp. In this type the bulb contains an inert gas whose function is to reduce the tendency of

tungsten atoms to evaporate from the hot filament; this they are partially prevented from doing by frequent collisions with the molecules of the gas. The efficiency of the gas-filled lamp is about twice that of the vacuum lamp.

Electric lighting is one of the few commodities that have steadily decreased in cost from the beginning, and this, it may be said, is solely the result of research. The improvements have, of course, taken place not only in the lamps themselves but also, to a very large extent indeed, in means for producing and distributing electric power, and today the cost of a given amount of light is but 5 per cent of its cost in 1880.

Improvements in electric lighting may, of course, be taken advantage of either to obtain more light for the same money or the same amount of light for less money. In this country we have elected to obtain more light. However, there was a time immediately following the introduction of the tungsten lamp when many central stations felt that they faced ruin because, as they argued, their lighting load would be cut to perhaps one-third of its then existing volume by the increase in lamp efficiency. But the fears proved to be wholly imaginary, for it was soon discovered that, quite generally, in factories, offices and shops, increased production could be obtained at a very slight increase in expense for better lighting. Thus experience gathered from many typical manufacturing plants indicates that while the entire cost of proper artificial lighting is of the order of 1 per cent of the wages of the workers affected, an increase in production of anywhere from 5 per cent to 20 per cent may follow its introduction. The safety of workmen is another important item. According to an estimate of one of the life insur-

ance companies, the equivalent loss to the industries by accidents chargeable to poor lighting may amount to as much as $300,000,000 per year, a sum which is said to be in excess of our yearly industrial lighting bills.

Last year purchasers of incandescent lamps in the United States paid approximately $90,000,000 for lamps with which to light homes, stores, factories and streets. This is equivalent to less than two cents per capita per week. If the present day intensity of lighting had been obtained by using the incandescent lamps of 1892, the cost of lighting in 1922 would have been increased one and one-half billion dollars and there would have been required 25,000,000 tons of coal additional to generate the current.

ELECTROCHEMISTRY

This subject is replete with illustrations of the interlocking character of scientific knowledge. Adapting a figure once used by Dr. W. R. Whitney, Director of the General Electric Company's Research Laboratory, it might be said that the value of a certain number of researches, so long as they are kept separate from one another, is purely additive. If they are coordinated however, so that the results obtained in each are available in connection with the results of the others, their value may be imagined as increasing as the square or cube or even a higher power of the number involved.

The topic of electrochemistry well illustrates this principle. On the one hand we have applied electricity, and on the other we have applied chemistry, both being of great practical importance. Between them is electrochemistry, drawing certain knowledge from the electrical

sciences and certain from chemistry, and constituting an entirely new science with distinct applications. Today the electrochemical industry is one of the largest, if not the largest, single user of electrical power. Regarding its importance the following statement of President F. J. Tone of the American Electrochemical Society written during the war is interesting:

America has long enjoyed a supremacy in electrochemistry, but in spite of the strong position of the industry before the war no one would have dared to predict the expansion which the war would demand of us. It has called for chlorine, cyanamide, air nitrates, and phosphorus in vast quantities. It has required the ferro-alloy industry, the electrode industry, and the abrasive industry to quadruple their outputs.

As a single example, consider briefly the contribution of electrochemistry and electrometallurgy to the aircraft program. The airplane motor has a crank case and pistons of aluminum. Its crank shaft and engine parts subject to the greatest strains are all composed of chrome alloy steel. All of these parts are brought to mechanical perfection and made interchangeable by being finished to a fraction of a thousandth of an inch by means of the modern grinding wheel made from electric furnace abrasives. Calcium carbide, and its derivative, acetylene, are making possible an ample supply of cellulose acetate for airplane dope. When the aviator trains his machine gun on an enemy plane, his firing is made effective by tracer bullets of magnesium or phosphorus. When our bombing planes begin to carry the war into Germany, it will be with bombs perhaps of ammonium nitrate or picric acid or other high explosives, all depending largely in their manufacture on electrochemical reagents. Without the pioneer work of Hall, Acheson, Willson, Bradley, and others, the present aircraft program would be impossible of achievement.

Then there is gas warfare, the very basis of which is

chlorine. Germany has long been a nation of chemists, and when she planned a war of frightfulness, it followed as a matter of course that she should seek to make it also a war of chemical frightfulness. Much as we deplore it, therefore, we have been forced to throw our best energies to the solution of the problems of gas warfare. It is interesting to note that chlorine, the product of the electrolytic cell, is the basis of mustard gas, chloropicrin, phosgene, and almost all of the important war gases. Thus does electrochemistry enter fundamentally into the modern military machine.

Arthur D. Little wrote some years ago, "To no chapter in the history of industrial research can Americans turn with greater pride than to the one which contains the epic of the electrochemical development at Niagara Falls. It starts with the wonderful story of aluminum. Discovered in Germany in 1828 by Wohler, it cost in 1855, $90 a pound. In 1886, it had fallen to $12. The American Castner process brought the price in 1889 to $4. Even at this figure it was obviously still a metal of luxury with few industrial applications. Hall in America and Héroult simultaneously in Europe discovered that cryolite, a double fluoride of sodium and aluminum, fused readily at a moderate temperature, and when so fused dissolved alumina as boiling water dissolves sugar or salt, and to the extent of more than 25 per cent. By electrolyzing the fused solution aluminum is obtained." In 1895 the manufacture of aluminum was started at Niagara Falls under the Hall patents. In 1911, the market price of the metal was 22 cents and the total annual production 40,000,000 pounds and by 1919 the production of aluminum had increased to 200,000 tons or ten times the amount in 1911.

In the words of Héroult: "It looks probable that after

the golden age, the stone age, the bronze age and the iron age, we will have the aluminum age." Aluminum is one of the most abundant of all chemical elements.

One of the most important of the electrochemical industries is the electrolytic refining of copper. A suitable process was the subject of long investigation, but today one of the forms in which the metal is most commonly available is electrolytic copper.

Electrolytic methods are also proving useful in the refining of silver. The crude material may consist chiefly of silver with small amounts of gold and other metals or it may contain considerably larger portions of gold as in crude bullion. Scrap jewelry, plate, etc., may also be handled, in which case there is a high percentage of copper and other base metals. Silver also occurs in nature in copper and lead ores. After the proper heat and chemical treatments, an alloy is obtained which may vary from 95 per cent to 98 per cent silver, and this alloy when passed through the electrolytic refining process yields silver crystals, which are at least 99.9 per cent pure. Electrolytic processes are in use in certain of the mints for the recovering of silver. The extraction and refining of gold electrolytically is also assuming important proportions.

The problem of recovering tin from tin cans and other scrap in which a thin layer of the metal has been employed to protect sheet iron from rusting, has received attention for a long time. It is now carried out electrolytically, about 90 per cent of the tin in the scrap being recovered; it is obtained in a form which is about 99 per cent pure.

Electrolytic refining of many other metals has also come into practice in recent years. The case of one of

these metals is particularly interesting in that the product obtained is reëmployed in the electrical industry. Electrolytic iron is very pure and has been found highly desirable in connection with certain transformer cores. For some years past the best loading coils have contained cores of compressed iron dust made from electrolytically refined iron.

Many of the chemicals of most use in the chemical industries are now produced electrolytically. Among these may be mentioned chlorine and potassium permanganate; oxygen and hydrogen may also be cheaply produced electrolytically where electric power is plentiful.

ELECTRIC FURNACES

The discovery of fire was one of the most important the human race ever made. Even in prehistoric times, man understood the art of smelting copper and bronze so that he was able to fashion crude instruments and ornaments from them. It was in historical times that the control of heat had been sufficiently mastered to enable him to recover iron from its ore and to melt it with sufficient ease to make it an important metal. Much of the progress in the industries since that time typifies man's increasing mastery of what might be called the thermal art. There is scarcely a process of manufacture which does not employ the agency of heat in one way or another.

Today the electric furnace stands as one of the most useful means of producing and controlling high temperatures. It is by no means obvious that this should be true, because at first sight, electrical heating would seem to be highly inefficient. It involves the use of the heat

energy of coal or gas to generate steam, the energy of steam to generate electric current, the energy of the current in turn being used to produce heat which, at best, is but a small fraction of that which might have been obtained directly from the fuel. There are, however, plenty of reasons why this offhand consideration of the electric furnace must not be taken as final.

In the first place, in a fuel-fired furnace, the heat of the fuel which is usefully used in heating the charge of the furnace may be as low as 5 per cent. On the other hand, in the electric furnace doing the same work, as much as 80 per cent of the heat generated may be usefully employed upon the charge. It is obvious that in any fuel-fired furnace, the gases of combustion must be discharged at a temperature which is at least as high as that of the charge and usually much higher. This means, especially in a high temperature furnace, that only a small percentage of the total heat of the fuel is usefully employed.

In the matter of attaining high temperature, the electric furnace stands almost without a competitor. The electric arc possesses the highest temperature of any artificial source. It is probable that the highest temperature which can be obtained in a furnace by the combustion of fuel is rather less than 2000° C., while the limit of temperature in the furnace heated by the electric arc is probably not much less than 3600° C. Furthermore, the electric furnace offers ideal conditions for the regulation of temperature, and supplies heat in a form which is entirely free from flames and gases whose presence in many processes would be extremely undesirable. Thus the use of electricity has made possible a vacuum furnace so successful that a temperature of 2500° C. may readily

be obtained, and a high pressure furnace in which a pressure of 2000 atmospheres may be maintained at a temperature of 2000° C.

It is not intended here to discuss the various types of electric furnaces, but to bring out their great usefulness in the industries. Here are some of the substances commonly or exclusively produced in electric furnaces: carborundum (silicon carbide), calcium carbide, phosphorus, ferrochromium, ferrotungsten, ferrotitanium and ferromolybdenum, ferrosilicon, ferrovanadium, graphite and certain refractories such as alundum. The ferro-alloys have become indispensable in the making of various steels. For example, ferrotungsten enters into the so-called high speed steels which will retain a cutting edge although heated to practically a dull red temperature by the work of cutting. It is estimated that their use has increased the output of machine shops from three to five times. Ferrotitanium is used in the refining of steel which is extensively used in automobile parts; ferrochromium enters into the very hard so-called "chrome steel" from which armor is made.

Electric furnaces of enormous size are also being employed directly in the making of steel. Two of the largest of these are installed at the U. S. Naval Ordnance Plant at South Charleston, W. Va. Each furnace has a holding capacity of 40 tons and at normal operation draws about 13,000 amperes in each of three phases, a total of nearly 40,000 amperes. Such furnaces are often used in connection with a Bessemer converter, the primary refining being carried out in the converter with the final stage taking place in the electric furnace.

It is interesting that the electric furnace has produced new refractories which could not otherwise have been

obtained. An example is found in the substance known as alundum or bauxite which is fused aluminum oxide. The melting point of this substance is about 2000° C. and the process of its manufacture is, therefore, one which must be carried out in the electric furnace.

A striking instance of the necessity of temperature control is found in the manufacture of carborundum or silicon carbide. Temperature determinations made upon different portions of a carborundum furnace while in operation, show that the carbon and silicon dioxide do not unite to form the compound SiC until a temperature of about 1840° C. is reached and that this substance spontaneously dissociates, giving off silicon vapor and leaving the carbon behind at a temperature of 2240° C. The temperature limits between which carborundum crystals are formed and dissociate are therefore only 400° apart. Electrical heating is, therefore, applied not only because of the high temperature required but also because of the necessary close temperature regulation. The carborundum furnaces in use draw 20,000 amperes at 75 volts, a power equivalent to an average railway locomotive.

Another instance of temperature control is found in the manufacture of cyanamide which is formed by heating calcium carbide in an atmosphere of nitrogen. The formation begins at a temperature of about 1000° C. and dissociation with the liberation of nitrogen takes place if the temperature rises above 1360° C. The control of the temperature in this process is complicated by the fact that the taking up of the nitrogen to form cyanamide in turn liberates a large quantity of heat.

FIXATION OF NITROGEN

The fixation of nitrogen which occurs in the making of cyanamide is one of the most important methods for the artificial production of nitrates. The large Government nitrate plant at Muscle Shoals, Alabama, was built for the production of ammonium nitrate by the cyanamide process, the capacity of the plant being 110,000 tons of ammonium nitrate per year. The Muscle Shoals plant was also equipped for the manufacture of the calcium carbide and the nitrogen gas needed in carrying out the process. The calcium carbide is obtained from large electric furnaces and the nitrogen from liquid air produced at the plant.

There are two other methods extensively in use for the fixation of nitrogen. That known as the arc process finds its greatest application in Norway where the single large Rjukan plant is stated to have an annual capacity of 200,000 tons of calcium nitrate containing 26,000 tons of fixed nitrogen. The arc process employs a fact observed many years ago, that in the presence of an electric spark, nitrogen and oxygen will combine to form nitric oxide, the formula for which is NO.

The power required is about 12 horsepower years per ton of nitrogen fixed and the process can therefore be employed only where electric power is extremely cheap, but it has the advantage of requiring, as raw material, only the two gases, oxygen and nitrogen, which are everywhere available as the chief constituents of the atmosphere. The cyanamide process for which Muscle Shoals was designed, requires about two horsepower years per ton of fixed nitrogen.

The Haber process produces ammonia gas by the direct

combination between nitrogen and hydrogen in the proper proportions. The union of these gases is effected by heating in the presence of a catalyzer (a necessary agent which is not consumed by the reaction) and not by the direct action of the electric discharge. The heating is usually carried out electrically as well as the procuring of the nitrogen and hydrogen required as raw materials. The nitrogen is generally obtained from the atmosphere by liquefaction as in the cyanamide process and the hydrogen may be obtained either by the electrolytic dissociation of water or by the dissociation which occurs in the making of water gas. The capacity of the two largest Haber plants in Germany was, prior to the great explosion of 1921 which destroyed one of them, a total of 300,000 tons of fixed nitrogen per year.

It is difficult to say, at the present time, just how important the nitrogen question is to this country. It has been estimated that the yearly loss of nitrogen from the soil by the removal of grain crops alone amounts to 2,000,000 tons per year and that only about 3 per cent of this is being returned in the form of organic fertilizer. The time, therefore, seems destined to come when the nitrate question will be an important one; but at present the supply from the natural beds of Chile and from by-product coke production may be sufficiently abundant to make artificial fixation on a large scale uneconomical.

CHAPTER IV

THE X-RAYS

R. W. King

During the generation which gave to the world the epoch-making theories of Maxwell and the experiments of Hertz, a new field of investigation came into prominence, the conduction of electricity through gases. By means of glass tubes through which electrodes were sealed and in which various gases, exhausted to any degree of pressure, could be contained, an extremely wide variety of interesting and curious observations had been made. The work began as early as about 1840 and has continued without interruption to the present day. Even in the early days, the field attracted many workers and the reports of researches began to pile up by hundreds and even thousands, but all without revealing any apparently significant facts.

In spite of this the faith of the investigators still abided. In a prophetic passage written in 1893, Sir J. J. Thomson said: "The phenomena attending the electric discharge through gases are so beautiful and varied that they have attracted the attention of numerous observers. The attention given to these phenomena is not, however, due so much to the beauty of the experiments as to the widespread conviction that there is perhaps no other branch of physics which affords us so promising an opportunity of penetrating the secret of electricity; for while

the passage of this agent through a metal or an electrolyte is invisible, that through a gas is accompanied by the most brilliantly luminous effects, which in many cases are so much influenced by changes in the conditions of the discharge as to give us many opportunities of testing any view we may take of the nature of electricity, of the electric discharge, and of the relation between electricity and matter."

One of the phenomena of discharge which received much attention at the time this passage was written was that of the "cathode rays." Years before it had been found that the discharge in a very highly exhausted tube is accompanied by the appearance of these rays emanating from the negative terminal. They cause a brilliant fluorescence of the glass wall where they fall upon it, and also appear to move in straight lines, for they produce a sharp shadow on the glass of any object—either opaque or transparent—placed in their path. It was also known that the position of the shadow is shifted by bringing a magnet near the tube, thus indicating that the rays are bent in traversing a magnetic field.

As is implied in the quotation just given, a determination of the nature of the cathode rays might be expected to shed much light on the nature of electricity itself. Two possibilities seemed to present themselves; either the rays must consist of ether vibrations or of minute particles. Continental physicists were largely inclined to accept the former view, and held that electricity can best be conceived of as a sort of continuous fluid. English physicists, and notably Sir William Crookes, favored the view that the rays consist of particles and that electricity itself may be corpuscular.

For several years each view had its protagonists; but

the complete confirmation of the corpuscular theory came in 1897, when J. J. Thomson in England and Wiecherts in Germany succeeded independently in measuring the ratio of the charge to the mass of the particles comprising the cathode rays. Each investigator obtained the very surprising result that the nature of the particles is not changed by changing the kind of gas within the vacuum tube or by changing the kind of metal comprising the cathode. In other words, these particles appear to form a fundamental constituent of all kinds of matter. The correctness of this remarkable result has been entirely confirmed by subsequent experiments.

It is interesting to see how extremely minute the particles of the cathode rays are. Thomson's measurements showed that each particle has a mass of about 1/2000 that of the hydrogen atom, while the charge which it carries is so small that, to constitute a current of one ampere, more than ten billion billion particles must flow past any point in a circuit every second.

To this tiny particle, of which all matter is at least partly composed, the name "electron" has been applied. It appears to be one of the *fundamental forms which electricity assumes.* The electric discharge through an evacuated tube is very largely carried by a stream of electrons passing from the negative terminal to the positive.

To turn backward a moment, it was but two years after the appearance of J. J. Thomson's prophetic statement given above that a discovery was chronicled which produced discussion and stimulated interest almost to the fever point in physical laboratories the world over. The discovery was of what appeared to be an entirely new type of radiation. Working in the University of

Würzburg, Roentgen produced a form of rays which seemed to behave neither like the cathode rays nor like light. He apparently came upon his discovery by observing the fluorescence of certain screens when placed near a vacuum tube through which a discharge was passing. To his surprise, the fluorescence persisted even though the tube was covered with cardboard and could therefore not be due to the visible light emanating from the tube. In a beautiful investigation which, for directness and thoroughness, is perhaps the equal of any ever recorded, Roentgen found that pieces of metal and other dense substances would cast shadows on a fluorescent screen, but that the rays from his tube could traverse with considerable freedom many bodies opaque to ordinary light. He found that as a general rule, the greater the density of the substance, the greater its opacity to this new agent. Thus the flesh of the hand was much more transparent than the bones so that a distinct shadowgraph of the bones could be obtained by holding the hand between the tube and fluorescent stream. Roentgen showed that the cause of this fluorescence, to which he gave the name X-rays, is propagated in straight lines from the point on the positive electrode which receives the rapidly moving electrons coming from the cathode. He tried refracting the rays by passing them from one medium into another but found that their tracks were not bent, nor could he deflect them by the strongest magnets at his disposal. The rays affected a photographic plate as well as a fluorescent screen, so that he was readily able to take shadow photographs.

The true nature of X-rays remained a mystery for twenty years. They resisted all attempts to refract them and diffract them after the manner employed in

experiments with ordinary light, and at the same time the fact that they were not influenced by a magnetic field indicated that they could not be corpuscular. Weight of evidence gradually accumulating showed that if the X-rays were a wave motion like visible light, their wave lengths must be extremely short, probably of the order of 1/5000 that of visible light. In 1915 it was demonstrated by the German physicist Laue, that X-rays could actually be diffracted when the proper conditions were supplied. He proceeded upon the brilliant hypothesis that the orderly arrangement of atoms in a crystal might affect a beam of very short light waves as the regular rulings of a diffraction grating do visible light. He knew that the distance between adjacent atoms in a crystal was perhaps 10,000 times as small as the distance between adjacent ruling on the best diffraction grating. It might, therefore, be, that a beam of X-rays, upon passing through a crystal, would be broken so as to form a diffraction pattern. These diffraction patterns, when looked for, were found immediately, and the hypothesis that X-rays are similar to light, but with a very much shorter wave length, was substantiated.

Out of these diffraction experiments on X-rays one of their most fruitful scientific applications has come. Their study has contributed directly to our knowledge of crystal structure, not only disclosing the exact distances which separate atoms in a crystal, but also the arrangement of the various chemical elements which compose the crystal. For example, crystals of common salt, known to the chemist as sodium chloride, consist of alternate atoms of sodium and chlorine placed at the corners of a minute cubic lattice, the side of one of the elementary cubes being only about 1/100,000,000 of an inch. Diffraction

measurements have also shown that the "harder" a beam of X-rays the shorter its wave length.

Knowledge of X-ray wave lengths has, in turn, made possible certain advances in the study of atomic structure. Today the physicist's ideas of atomic structure and particularly the formation of the nucleus of the atom are taking quite definite shape. This subject will be touched upon presently.

X-ray photographs of broken bones and bits of metals embedded in the human flesh are now familiar to everyone, and the X-ray as a means of diagnosis is assuming more and more importance. By its use tuberculosis and various types of tumors can be recognized, and it also makes possible observations of the functioning of many organs of the body. There is no dollars-and-cents measure of the blessing which the X-ray is to mankind, simply as an aid to diagnosis, but so long as accident and disease are known our indebtedness will steadily accumulate.

Early workers with X-ray apparatus noticed that the radiation produced certain physiological effects. In many cases these were discovered too late. X-ray burns may easily prove fatal and the toll of scientific martyrs who gave their lives to extend our knowledge in this field is both a long and distinguished one.

There grew out of the early and disastrous use of the X-rays the belief that when properly controlled, this new radiation might be very helpful in curing certain diseases. This opens up a vast field for research, and it will doubtless be many years before anything like the whole story can be told. Certain definite and valuable curative properties have already been determined, however. There are some types of skin disease, for instance, which yield quite readily to X-ray treatment, but the

larger problem of eradicating deep-seated tumors has thus far proved a difficult one and it is impossible to foretell how valuable X-rays may prove in this connection.

THE BORDERLAND OF ELECTRICAL RESEARCH

It is often said that research is of two kinds. Certainly there are many reasons for making a distinction between *pure* science and *applied* science. Pure scientific research is conducted with the philosophic purpose of extending human knowledge. Applied scientific research has as its goal the meeting of some human need, either present or anticipated. Investigators in pure science have been likened to explorers who discover new continents, or islands, or hitherto unknown territory. Theirs is a task of pushing forward the frontiers of knowledge. They are the advance guard of civilization. Their results are the raw material out of which the engineers and other workers in applied science are fabricating manifold devices to meet human needs and raise the standard of living.

Having surveyed the well-established fields of applied electrical research, let us turn and examine for a moment some of the outposts where the most fundamental discoveries are being made.

Everyone, at one time or another, has met the term "atom" and understands that it is the smallest particle of any substance (that is, any chemical element) which can exist and still retain the properties of the substance. Whenever we have thought of the atom in this way, we have probably found it hard to resist the temptation to wonder what would remain if only we could find a knife

so sharp, or a hammer so destructive, that we could break even the atom into smaller pieces.

If we could do so, what would we have left? Modern physics furnishes the answer. It gives a rather complete picture of just what there would be left. Not only is the subdivision of the atom occurring spontaneously in Nature in the phenomenon of radioactivity, but recently Sir Ernest Rutherford has succeeded in taking apart—it would perhaps be more exact to say, knocking apart—atoms of nitrogen, aluminum and several other elements.

There can no longer be much question that the two structural units, the two *ultra atoms* they might be called, are the electron on the one hand, and the nucleus of the hydrogen atom on the other. Hydrogen is the lightest of all the chemical elements and it now appears to be a component of all these elements. To the nucleus of the hydrogen atom, because of its apparently universal significance, the separate name "proton" has been given. It is indeed a surprising and yet a very satisfactory outcome that the list of some ninety chemical elements—many of them as found in nature possessing fractional atomic weights—should be composed of just two things, electrons and protons.

Before describing the structure of any particular atom, certain characteristics of the two ultra atoms must be mentioned. The electron, no matter where found, always carries a minute charge of negative electricity of absolutely invariable amount. Whether the electron is anything *but* a little speck of negative electricity still remains to be determined. The weight of evidence thus far indicates that, if it contains a nucleus of matter, this nucleus is indeed extremely small. The proton, as might be expected, carries a charge of positive electricity which

is exactly equal to the negative charge of the electron and the two, when associated in equal numbers, therefore, neutralize one another electrically. The proton, however, is some 1800 times as heavy as the electron and may very likely possess a nucleus consisting of an appreciable amount of something similar to what we ordinarily refer to as matter. On the other hand, it is not impossible that the mass of the proton may arise entirely from the positive electricity which it carries.

With the electron and proton as the two structural units, the internal arrangement of a typical atom can be readily pictured. It is frequently referred to as a miniature solar system. There is good reason to believe that at the center of every atom there is a nucleus. This nucleus, in every case except hydrogen, contains both electrons and protons (but more of the latter than the former) which are very intimately held together by forces of which little is known. Since the nucleus contains more protons with their positive charges than electrons with their negative charges, the nucleus manifests a positive charge. Circulating around the nucleus in orbits, the exact shape of which is still subject to conjecture, are individual electrons, the number of which is equal to the deficit of electrons in the nucleus. The atom as a whole therefore contains an equal number of protons and electrons and is electrically neutral.

The number of ultra atoms which make up the normal atom of any particular chemical element is, except for the so-called isotopes, invariable. For example, every normal oxygen atom always contains sixteen protons and sixteen electrons, there being sixteen protons and eight electrons in the nucleus and eight electrons circulating in orbits. There are more protons and electrons in an

atom of a heavy element such as gold or platinum than in a lighter element such as aluminum or nitrogen. Thus, the nucleus of helium, which is the lightest of all the elements next to hydrogen, contains four protons and two electrons and there are, therefore, two orbital electrons in the complete atom.

With the help of this quite definite picture of atomic structure, physicists and chemists are now trying to relate the many physical and chemical properties of each of the atoms to particular arrangements of the orbital electrons. Many important researches are centering around this general problem.

CONCLUSION

Whither these researches will lead it is now impossible to say. It may be that the writer of a generation hence, who is making a plea for the value of scientific research, will find his star illustration here in the field of atomic structure. However, in our acknowledgment that the future is beyond our ken we may find reason for rejoicing. It means that progress in pure science has not ceased. Pure science must ever be the forerunner of applied science. Without the results of pure science abundantly available in his library, the applied scientist would either have to fold his hands and wait, or change his spots and do the work of the pure scientist, not his own.

This is an important point. So great has been man's success in turning scientific discoveries to account that a strong temptation confronts him to seek knowledge because it is useful and not simply for the love of knowledge itself. Herein lies a danger of losing the true perspec-

tive. It may be but a step from seeking knowledge because it is useful, to seeking useful knowledge, and no touchstone has been vouchsafed man by which he may at once determine the usefulness of the discoveries he makes. The practical value is often slow in being brought to light. Had William Gilbert been interested in practical values, we may reasonably doubt whether he would have bothered to make his many observations on the attraction and repulsion of magnets from which springs the modern science of electricity; and had Georg Simon Ohm been seeking useful knowledge, we may question whether he would have undertaken his painstaking analysis of the similarities between the flow of heat and the flow of electricity, thereby arriving at a law which probably is used more frequently than any other single principle in the whole field of electricity; and again, had practical motives been the actuating ones, it is doubtful if Maxwell, with paper and pencil, would have elaborated shrewd guesses as to the structure of the ether, a work without which there could be no wireless telegraph or telephone.

Take from the structure of our present-day electrical industry the processes that are based in one way or another upon the academic researches of Oersted, Ampère, Faraday, Roentgen, Ohm, Heaviside and many others—all of which were done without thought of their possible applications—and we are at once transported back to the days of James Watt and his primitive steam engine. Woven through and through our vast industrial fabric is no end of evidence pointing to the conclusion that the abstract scientist and the reclusive philosopher of one generation are preparing the way for the technician of the next; in a word, that for the guiding of research

there is no higher principle than this: "Know the truth, and the truth shall make you free."

But here follows another conclusion of equal importance. If there is to be scientific research, there must be men to carry it forward. To quote from a passage by Doctor F. B. Jewett, vice president of the Western Electric Company, in which he speaks of the laboratories of the Bell system:

> Even today and despite the aggregation of human and material resources which have placed our laboratories in the front rank of industrial research organizations, there are on my list a large number of problems which we are not in a position to undertake. These problems, which are directly and solely in the communication field, are problems of major interest to the industry and are of such a nature that we are absolutely sure they can be solved with positive results of inestimable value to the telephone and telegraph companies and to the public at large, provided only that their solution can be obtained through the application of well-organized industrial research. Why, then, do these problems lie essentially untouched? Is it because of a lack of material facilities, of money, of courage to go ahead, or the feeling that these particular researches will not recommend themselves to the business men who are responsible for the commercial destinies of the telephone and telegraph systems? It is none of these. There is no lack of money, no lack of material facilities, no lack of courage, no lack of approval on the part of the directors, for we have long ago learned that material facilities are easy to obtain.
>
> What, then, is it that should stop us from an immediate attack if we are so sure of the ultimate result? The answer is the simple, three-letter word, "men." Not mere human bipeds but men endowed by nature with at least a modicum of the spirit of scientific research to which has been added, either through fortune, personal initiative, parental solicitude

or a far-sighted policy on the part of the state, that orderly training and opportunity for expansion of intellect without which natural talents are of little avail.

Our case is typical of the situation which confronts every industrial research organization on the continent. The matter of an adequate supply of properly-equipped and trained investigators and directors of research is absolutely vital to the growth of industrial research and I am sure as one can be of anything in the world that all of our visions of the benefits to be derived from a large expansion of industrial research will come to naught if we fail to realize or neglect the fact that in the last analysis we are dependent absolutely upon the mental productivity of men, and men alone, and that we must in consequence provide adequately for a continuous supply of well-trained workers.

Dr. Jewett adds that by their nature industrial research organizations are essentially man-consuming as distinguished from man-producing agencies.

The work of the universities and other institutions of higher learning is therefore twofold. Theirs is the responsibility, in the first place, of carrying on the pioneer investigations without which our knowledge of natural laws would not increase, and in the second, of developing and training a supply of competent young men from whom both the faculties of the universities and the personnel of the industrial laboratories can be recruited. This view, while it implies that as the industries expand our seats of learning shall be allowed to expand with them, does not exact responsibilities different in kind than those they have always borne. Nor need we attempt to decide which aim is of the greater importance; that is, whether effort should be directed primarily to the training of investigators or to the searching after new knowledge. The two aims are entirely compatible.

It makes no difference which of these we place first. If the universities are provided with all the necessary means to carry on the work of pure research, so that they may continue this on an ever increasing scale as ably as they have conducted it in the past, we may be confident that they will, in that very act, become sources of well-trained investigators for the industrial laboratories. On the other hand, in so far as they properly carry on their work of educating and training, the universities will become, of necessity, those springs of basic knowledge without which the industries cannot properly advance.

CHAPTER V

EARNING POWER OF CHEMICAL RESEARCH

H. E. Howe

The future security of industry depends in a large measure upon ability to develop intelligent, educated workmen and directors who appreciate and apply science. Facilities for education have, very fortunately, made it increasingly easy for any man to become better informed on subjects pertaining to his work. Fortunately also more and more men whose duty it is to direct business affairs have come to know that research in the natural sciences and the applications of the results give them the most potent anchor to windward. However to most men of industry and business, science is still an interesting and important thing—for the other fellow. It is merely theory, whereas they insist upon something practical. We propose to indicate by example that science is not only practical but a necessity in any constructive work involving materials.

The man who has never given a chemist, a physicist, or a biologist, an opportunity to solve his production problems is often surprised to find how easy it seems to be to help him. Dark mysteries suddenly disappear or may be the scientist proceeds to break up the problem into factors which are worked out one at a time. The word "research" is often used in discussing scientific work

and describes pioneering effort in new corners. It has been defined as a question put to nature, the answer being sought by the investigator. Many questions can be answered from present knowledge. Those which can not, involve research into the unknown, with the result that when successful our boundaries of knowledge are extended.

Have you ever seen tea turn black upon being sweetened? It happened in Newfoundland. Molasses or syrup was used to sweeten tea in that place and the business was worth getting. A dealer desiring to please an importer sent him a better grade of syrup than had been specified, in the hope that his trade might be won. Imagine his surprise at receiving a long complaint instead of expected praise. When put into tea it became as ink! At length a chemist was consulted. He knew that when a solution of iron is added to one of tannin a black color and even a precipitate is formed at once. He knew that tannin is to be found in tea, but whence the iron? Why had it not occurred before? The answer was found in the origin of the syrup. Barbados syrup was ordered. Louisiana was supplied. Syrup is concentrated in copper in Barbados—in iron in Louisiana. For most uses the Louisiana article is superior, but not for tea! The chemist was not long in solving the mystery.

A manufacturer was spending about $1000 per year for a boiler scale preventive. He knew it would be more expensive to have the scale form in the boiler but he did want to know more about the compound and why the little he used should be worth the cost. Knowing that chemists have ways of taking things apart to learn their composition he arranged for an analysis. And when he heard that the solution was 3 per cent molasses and

97 per cent water, he exclaimed, "Now I know where the Gentiles got the money that we Jews get from the Gentiles!"

One day a traveling salesman offered a master mechanic a solution for removing oil and grease from belting. It improved the leather. It was safe to use, being non-inflammable. Also it was $10 per gallon and you had to have enough to soak whole belts! In the midst of things the works chemist chanced along. Being asked to see the solvent, he smelled it and at once identified it as carbon tetrachloride, then worth about $1.25 per gallon! In fairness to the salesman it should be said that he did not know what he sold. He had only been told what the solvent would do.

A pulp maker grew tired after awhile of having to suffer because of poor quality. His pulp was the very worst on the market, while his output was so large that a few cents a ton made a difference of many dollars per day. His greatest trouble was due to dirt specks which sometimes ran as high as 30,000 per square foot of pulp. A scientist was finally allowed to look around. He found a few sources of mechanical dirt removable by screening, giving results which won him a new lease on his job and the real work began. Eventually through research he learned that with the aid of refrigeration one of the chemicals used could be made of such strength that lower pulp-cooking temperatures could be used, thus causing the least disintegration of dirt-producing parts of the wood, such as bark. Then he found out more about using this chemical reagent to make better pulp. Next came better and cheaper bleaching and today the product of that mill is standard. The pulp is the world's best. The dirt specks are below 20 and on special order quantities

have been supplied carrying less than 12 per square foot. That company is firm in the belief that properly directed and sustained research gives a wonderful advantage over others who do not employ it. For them, as well as for others, it has meant lower costs coupled with a quality so satisfactory that when purchases are being curtailed their competitors are the first to lose business.

Do you remember the first tantalum filament electric lamp you saw? And then the tungsten? The first question was "What is it?" the next "Where can I buy them?" But they were fragile lamps; could only be used in certain positions, and while the light was excellent its cost was high owing to filament breakage. This was due to the fact that tungsten melts at so high a point and is so difficult to work that these fine lamp filaments were not continuous wires but composed of small particles merely pressed together. The task became to produce ductile tungsten. The prize was the incandescent lamp business of the world. The competitors were groups of American and German scientists. The contest was actual and real. It was scientific research of a difficult sort conducted under great pressure. Here was an order for an invention and usually the best scientific work is not done under such conditions. It seems better to keep working with an eye on all results, knowing that all true knowledge is worth while.

In the end the Americans won and we all know the "Mazda" lamp. Another piece of work was begun, not under order but for the sake of a scientific truth. This time what was wanted was to know something of the electrical conductivity of inert gases, those gases which show little or no inclination to form compounds with other materials. It was found that filaments have very

long life when heated to incandescence in such gases and give better colored light as compared with lamps in which there is a partial vacuum. Nitrogen and argon are now largely employed in gas filled lamps. The consumer gets the benefit of more light and better light for his money. It has been stated that if the illumination of 1922 had been secured with the best type of lamp available in 1892 the cost would have been $2,000,000,000, or $1,500,000,000 more than it was. Surely research has paid all concerned in this instance!

Then came the time when those studying the art of communication desired so to extend the radius as to talk across the continent. Some sought to make loud transmitters so that a feeble wave could be heard. But that would have necessitated rebuilding all telephones to be used for really long distance. It was known that there are losses along the lines and we can remember when it was thought necessary for one to go to "central" to engage in the then long distance telephone conversation. One group decided to try to find ways for balancing the lines and supplying extra energy from storage batteries to make up for losses and to amplify the sound waves set up when one speaks into the transmitter.

All this time research was in progress on electrons, as the tiny particles of electricity are called. This academic study resulted from the discovery of the radioactivity of some chemical elements and compounds. It was found that electrons may be used to control large masses of energy, building up and up until the final waves are billions of times as strong as the original waves and they have not changed in form. Thus we speak into an ordinary telephone, setting up vibrations on the diaphragm of the transmitter. The resulting waves influence the

electrons in an audion tube which admits energy from a storage battery to strengthen the original waves a hundredfold. These pass on in like manner and are multiplied by a hundred. We soon reach the billions and all the time the wave has the same essential characteristics of form.

This plan and method were successful. Today any telephone is a long distance instrument and without change in the telephone itself, its effectiveness has been increased a thousand times because science, fully supported over long periods of research, was at work. Every telephone user was a beneficiary. The gain over cost has been and will continue to be enormous.

All these are instances varying in the magnitude of the dividend on industry's investment in research. Now let us consider some of the ways in which business is assisted.

CREATING NEW INDUSTRIES

Research creates new industries. It creates them because it finds new materials and then devises ways to use them. The two steps are not necessarily connected. In fact they are nearly sure to be separated by long periods of time. We know now that in the atmosphere there are at least seven gases besides moisture. These are oxygen, nitrogen, argon, neon, xenon, helium and krypton. These gases were first nothing more than newly discovered elements. Their importance to life was first recognized and in time it became desirable to know how to separate these gases on a commercial scale. Industrial uses had been found for them. When available in quantity more and more uses have been found with still more in prospect if much lower costs can be attained.

As a result of research the problems began to be solved. Along in the 80's and 90's we heard much of liquid air which has found very few of the applications predicted for it but its preparation has become very important as the method for gas separation. This is due to the differences in boiling points of liquid gases. When we learn more about the cheap liquefaction of air we shall begin to have oxygen cheap enough to become a factor in such processes as the blast furnace, where vast quantities of fuel are required.

Several firms are busy with the preparation and use of these gases of the atmosphere. One of them is a ten-million-dollar corporation.

Research upon helium, carried on by the Bureau of Mines, has been very successful. Before the war helium brought $2000 per cubic foot and about fifteen cubic feet were available. During the war, when the work was still experimental, this cost was reduced to from $300 to $500 per thousand cubic feet and since then to from $80 to $100 for a like quantity. Specialists expect eventually to achieve a cost of $30 per thousand. This work has given the United States a real monopoly of the only non-inflammable gas suitable for aeronautical purposes.

Oxygen performs its work in industry by making possible dollar-saving methods involving other gases and materials. High temperatures required in welding are attained with oxygen and hydrogen or acetylene. An outstanding example of economic results is the success of Americans in welding the German ships injured by their crews just before war was declared. Clever welding made it possible to effect repairs in months, whereas it had been thought that years would be required, and hav-

ing worked out the best method for one ship it was comparatively easy to complete the others as nearly all were injured in the same way. The blowpipe is frequently the best method for cutting up waste metal, for clearing away fallen members and for disentangling wrecked structures. Massive machine parts are sometimes roughed out of slabs by the oxyhydrogen flame making possible working parts that could not be fashioned otherwise. Research, then, on oxygen is easily translated into real profits in industry.

Argon has been employed unexpectedly in the electric lamp field. It affords us a good example of how research undertaken primarily for the sake of ascertaining new truths may at any time be found to have yielded a big income upon the investment. Experienced business men come to know that by keeping a number of promising problems going they are reasonably sure to win enough prizes to more than repay the entire venture.

In the chemical element, sulphur, we can find illustrations of the many ways in which research and applied chemistry have been turned into substantial bank balances. To begin with, sulphur had been obtained exclusively from Italian ores by a laborious process until an American chemical engineer solved the problem of pumping sulphur about 99 per cent pure from the great beds which underlie portions of Texas and Louisiana. It had been known for some time that these beds existed and both life and fortune had been lost in an effort to reach these deposits by the ordinary means. Layers of quicksand and toxic gases made this impossible. Then the chemical engineer conceived the idea of liquefying the sulphur a thousand feet below the surface and forcing it through one of a series of concentric pipes by means of

compressed air. Superheated steam and the air were to go down the outer pipe and the liquid sulphur was to come up through the center pipe. Sulphur displays peculiar characteristics when melted. It first liquefies and becomes quite fluid. If heating is continued it soon turns into a viscous, sticky mass which is most difficult to control. The success of the venture depended upon the ability to control these conditions so that the liquid sulphur might flow freely within the narrow temperature limits. The technical difficulties to be overcome were such that failure was freely predicted. However, one day the sulphur began to flow. The plant was shut down for slight adjustments and for weeks could not be made to operate again. But it *had* operated and there was no lack of determination to make it do so again. Eventually the sulphur started once more and from that time on fortunes began to grow. There are now at least three powerful companies obtaining sulphur by this method sufficient to meet the world demand.

In this connection it is interesting to note the influence this process had upon world markets. The Italian sulphur had been under the control of a British syndicate and when its representative reported that Americans were pumping purer sulphur from the ground, the agent was at once dismissed for having passed on to his superiors this sample of American bluff and nonsense. It was not until the syndicate's pocketbook had been affected to the extent of a million pounds sterling that they were convinced that Americans were pumping sulphur. It was only the generosity of the American concerns in agreeing to prices for sulphur which would allow the Italian industry to carry on that enabled these poor miners to continue to make their livelihood.

Now let us consider some of the ways in which this sulphur under the guiding hand of chemical research and chemical engineering proceeds to create still other fortunes.

When Goodyear conceived the idea of providing everyone with overshoes and rubbers he met great difficulty due to the fact that in warm weather the overshoes literally ran off the wearer's feet. He realized that some way must be found to harden rubber and still keep it elastic and pliable. He began a series of experiments and one day by accident dropped some rubber with which sulphur had been mixed upon a hot stove over which he was working. The result was vulcanization and from his keen observances of what took place at that moment there has grown up the rubber industry as we know it today. It has been estimated that every stormy day in New York City is worth one million dollars to the manufacturers and retailers of overshoes, rubbers, and raincoats, while figures involving other rubber products go quite beyond our comprehension. The Goodyear method for vulcanization continues to be the most important, but sulphur in the form of sulphur chloride has also been used. Antimony, another chemical element, finds a limited use, but sulphur continues to be the important vulcanizing agent.

The presence of sulphur has also presented a problem for the chemist, notably in the case of petroleum. The same engineer who obtained sulphur by pumping it from deep deposits had much to do with the elimination of objectionable sulphur from crude oil. This became a very important matter when kerosene lamps were so largely used for house lighting. If kerosene made from sulphur-bearing oils was used the odor of the burning

sulphur was not only discernible but highly obnoxious and even dangerous. Oils from certain Ohio and Canadian fields were worth next to nothing at that time. Chemical experiment led to a satisfactory and economic process for the removal of this sulphur, the oils being treated with a mineral oxide which was turned into sulphide by the sulphur. The oxide could be recovered by burning off the sulphur. With the introduction of this method oils from the fields mentioned shot upward in price and it is difficult to estimate the resulting benefits. At the moment the price rose from sixteen cents to over a dollar a barrel. Since then we have continued to use sulphur-bearing oils to the benefit of the immediate producers and of those in a community depending upon the industry for their income.

We do not know as yet why sulphur compounds are so destructive to insects and to fungi, but the fact remains that literally millions of dollars have been added to the returns of those producing fruits, vegetables, and farm crops because chemical research has provided sulphur in convenient form for use as an insecticide and fungicide. Sulphur was first used in this connection in a dip for sheep to destroy the tick. One day in desperation an orchard owner who saw his best trees dying from San José scale used the exhausted sheep dip on these trees. This was the beginning of what is now universal practice in the use of lime-sulphur solution or dust or other type of sulphur-bearing material in fighting these various enemies of horticulture. The use of flowers of sulphur for the same purpose is well known, and experiments are about to be undertaken using sulphur upon seed in an effort to control smut and scab in the case of potatoes.

Research has demonstrated other agricultural uses for sulphur. It is well known that sour and acid soils make the raising of some crops impossible and lime is used to correct this hyperacidity. It has also been found that soils can be too alkaline for the proper growth of potatoes. Researches now in progress and nearing completion indicate that sulphur is one of the best reagents for obtaining that degree of acidity which insures the growth of scab-free potatoes. Chemical research again is to be credited with assisting the plant scientists in determining the proper degree of acidity for the tubers. This has been reduced to the simple procedure of adding a synthetic dyeing material to the solution obtained by shaking a sample of soil in water and determining from standard data what may be expected with the acidity indicated by the change of color which results. The economic importance of this type of research is great, indeed, since some day we may be able to allocate the growing of certain crops to those lands which are best suited for them. When we take into consideration the excellent work being done by the plant pathologists in determining the relation of temperature to plant diseases the picture broadens. Thus smut has never been found in a Texas onion field, while it constitutes one of the greatest menaces to onions grown in the district of Chicago.

Sulphur is, of course, the starting point in the manufacture of sulphuric acid which is one of the most fundamental of chemical products affecting a great many industries. It is interesting to note that the use of sulphuric acid itself on alkali desert soils has given results in an experimental way which are more than interesting. It was found that treatment with acid not only neutralized the excessive alkali but otherwise rendered the soil

fit for agricultural purposes including desirable changes in its physical characteristics.

That new industries are created through chemical research is easily demonstrated in many lines of endeavor. Among the more recent efforts we find the hydrogenation of oils. Chemists have long known that the difference between the hard fats like lard and the oils, such as cottonseed or peanut oils, is only a couple of atoms of hydrogen in the molecule. It may be well to recall that the relationship between the atom and the molecule is analogous to that between the letter and the word. The word formed depends upon the way letters are assembled and by rearranging letters new words can be made. Molecules are likewise made by aggregations of atoms and the properties of a chemical compound depend not only upon what these atoms are but how they are arranged. We shall have something to say a little later as to the ability of the research chemist to rearrange these atoms to meet specific needs. In the case of fats, whether solid or liquid, the atoms involved are those of carbon, hydrogen, and ogygen. The problem was how to add to the molecule representing the oil, the two hydrogen atoms required to turn it into a hard fat. In the end it was found that this could be accomplished under certain controlled conditions of temperature and pressure if the oils were sprayed countercurrent to the hydrogen over a finely divided metallic substance usually a form of nickel. This metal, called a catalyst, undergoes no self change during the process and is recovered from the new product for reuse. It has been properly described as a chemical parson since it officiates at the union of various chemical elements but does not become a member of the new family.

We have as yet scarcely realized the importance of hydrogenation for, thanks to our resources, we have not yet met an emergency where its great value has been emphasized. While hydrogenated oils or fats do not contain some of the unidentified factors now believed to be essential for body growth, they nevertheless can be used in the place of many animal fats and should be considered supplementary sources of hard fats rather than substitutes. Chemical research through hydrogenation has elevated many ordinary and inexpensive oils to more exalted uses. It has advanced some oils out of the class of raw materials for technical purposes, such as soap-making, to the class of basic materials for food products. Likewise it has brought into business use inferior oils heretofore of little value. For example, when ordinary fish oil is used for soap-making the resultant product is good excepting in one particular. Articles washed with such soap retain a decided fish fragrance. When fish oil is hydrogenated it is still useful for soap-making, but hydrogenation has relieved it of its characteristic odor. Many oils are suitable for hydrogenation and some day the process may be used for simplifying some steps in refining. Hydrogenation is one of the many examples where research has devised a process with millions in it.

RESEARCH ON FUNDAMENTALS

The manufacturers who have derived the greatest benefit from scientific research have been those who have been willing to support what is known as pure science or genuine fundamental research without the expectation that black figures will appear on the cost sheets the next day. It is important to consider the relation of pure

science to industry, and in this connection Dr. W. H. Bragg, the eminent British physicist, has said: "It is easy and fascinating to suppose that a new invention is found as complete and clean as a nugget of gold, as unexpected and as unconnected with its surrounding, and finally as readily convertible into cash. The truth is very different. Science does not increase by the constant addition of new facts to old, as a library collection increases by the addition of new books or a museum by the addition of new specimens and curios. Science grows like a tree which shoots out new branches continually and at the same time strengthens the old, always growing higher into the light. Like the tree, science needs wise cultivation. The nourishment of the tree, its training and pruning, have their true counterparts in science. In both, the fruits come as the reward of skill and labor.

"The fruits of science are first seen when they are brought to market and it is vaguely supposed they were picked up *somewhere* and *somehow* in the condition in which they appear. Perhaps they were made by the man who carries the basket. It is not realized that the fruit comes at the end of a long process and that even a little application of science may be the result of unseen labor and growth for many years.

"It is not so easy to develop scientific results as to grow an orchard. The growth of science is not so much under our control as the growth of nature."

Instances of where such research has paid will be illuminating. In his work the organic chemist is particularly interested in those substances which crystallize. When in the course of research the end product forms beautiful crystals it is the end of a perfect day for him. This tendency was largely responsible for the fact that

industry waited until some ten years ago for synthetic resins now found in many articles of commerce. When certain reactions are carried on with two poisonous liquids, carbolic acid (known to the chemist as phenol) and formaldehyde, a sticky, gummy condensation product is formed. It remained for observing chemical engineers to see in this mass the possibility for commercial application. When the research work was repeated conditions were found under which maximum yields of suitable materials could be obtained, and now we find synthetic resins the product of a prosperous American concern. We meet the product in everything from cigarette holders to automobile electric systems and from jewelry to lacquers. As usually happens when material of this kind is available in quantity, new forms are developed and new uses found, so that today there is material for molding with metal or other parts in place, solid material, clear or variegated, from which shapes are turned, and the lacquers which are particularly effective as surface coatings.

In surface coatings themselves we have excellent examples of how research is carrying on the fight against rust and decay. Victories have already been won, notably in largely overcoming the tendency for metal to corrode. It is due to this tendency that much of our trouble and an annual loss of millions can be traced. There is the case of the building in New York City where it was found that all water pipes were badly corroded and unless something could be done new plumbing would be required. Is it any wonder the owners were in despair, and when they found that most of the pipes were imbedded in walls they were ready to give up? Then some one thought of chemical research and was fortunate in obtaining a well-qualified investigator. He rea-

soned that the long life of the pipe had been due to the fact that years ago water was not aerated. The increase in the rate of corrosion was due to the excessive oxygen in the water. He knew that oxygen and iron have an affinity for each other and combine as iron oxide, familiarly known as rust, whenever the occasion presents itself. He decided that if this oxygen could be satisfied with iron before the water entered the pipes, corrosion ought to cease. A container was filled with removable iron plates put there to be rusted. The water was conducted over these plates before it entered the pipes. Corrosion ceased, and the cost of a large building saved to the owners. Nowadays it has become the practice of engineers to reduce the oxygen content of water to zero before introducing it into pipes. This is done partly by mechanical and partly by chemical methods and means the annual saving of large sums of money.

The other line of attack is to produce noncorrodible metals and this is so fascinating a field for research that new alloys frequently make their appearance. Some of the most successful run into large annual production and have well-known trade names. Their development has created very favorable bank balances.

Research has contributed remarkable advances in the protection of metal by devising glazed coatings and enamels which show surprising resistance to wear and which have coefficients of expansion so nearly in accord with those of the metal that these glass-lined tanks and containers are used under many exacting conditions. Another line of defense has been protective coatings in the form of lacquers, paints, and varnishes for which gums have been brought from the ends of the earth. The conditions are exacting and it is only through the applica-

tion of science that most of the difficulties have been overcome. The great paint and varnish industries are therefore founded upon chemical research and they hold their position in the front rank because they continue their research.

In line with the development of these coatings the chemical engineer has contributed to their conservation and use. The development of spraying methods and devices and the extensive use of dipping comes back to his accomplishments. The continuous baking ovens owe their existence in large measure to his development work. The introduction of these systems has been known to save as much as 50 per cent of the materials formerly required and has reduced labor costs by an even greater amount. The recovery of the solvents expelled during the heating and drying process has offered a still further opportunity which has not been neglected.

Another important money-saving achievement has been the development of an enamel in which no inflammable solvents are used. Research in colloidal chemistry has made great strides in recent years and has been utilized by the research chemist in developing an enamel or lacquer in which the constituent gums are emulsified in water. Satisfactory coating is obtained by dipping. Electrically controlled ovens do the baking and satisfactory work is accomplished with all fire hazards eliminated.

There are other industries, notably rubber, where great quantities of solvents are necessarily employed. Their loss a few years ago constituted one of the big items of cost. Research in chemical engineering has solved the problem and in this solution a vital point has been the submersion of pumps in oil so that premature condensa-

tion would not take place. Under war conditions when the plant was being run to capacity one of the large rubber concerns recovered something like 20,000 gallons of solvents per day.

Solvents are being eliminated in some rubber operations by the use of natural rubber latex preserved in ammonia, an introduction of 1923. The use of this material grows out of scientific investigations on the varying quality of plantation and wild rubber coagulated with smoke in the original manner or by acetic acid. One of the variables is the protein of rubber latex found in some stage of decomposition in cured rubber. This protein is a protective colloid and ammonia is a perfect preservative for it. So ammonia is put in the collecting cups on the trees and the latex is shipped mixed with ammonia. Such fresh latex can be used as a cement without a solvent and, when dried, yields a "sprayed" rubber with characteristics opening new fields to the uses of rubber as well as affording a rubber believed better for most if not all its present purposes.

FUELS

Research has just begun to play its part in the fuel problem. It is unsafe to predict what the fuel of the future will be, but it is safe to say that results already achieved through research will have an important bearing. One fuel developed under war conditions did not have an opportunity to prove its utility. This is best described as colloidal fuel since the coal in it is reduced to that state of fineness which is known as colloidal—particles so small that when viewed through a high power microscope they exhibit a certain continuous movement

known as the Brownian movement. By the introduction of such coal into fuel oil the number of heat units per gallon of oil is increased and a further important point is that solids which of themselves are unsatisfactory as fuel become useful in this combination. This includes many waste materials which heretofore had been nothing more than a nuisance.

The principle of ore flotation is being applied to the fuel problem. The separation of the valuable material from the waste in ores is accomplished by the use of certain oils, films of which surround the particles, causing the material of value to float while the refuse sinks. Curiously enough, when treating coals so high in ash as to render them unsatisfactory for use, it is the ash which floats away and the coal which remains behind. The oil may be recovered for reuse or may be burned along with the combustible part of the fuel treated, as may prove most economical. Only one commercial unit is now in operation on the process but if it proves successful the possibilities are extensive. It means the reworking of many culm piles, and, perhaps, in the future the cleaning of coal at the mine so that transportation which promises to be expensive for some time to come may involve only 100% burnable coal. The actual value then of this research can be imagined but scarcely computed.

But this does not tell the whole story of chemical research applied to fuel and the resulting possibilities. There are many who see in industrial alcohol the only hope for the future maintenance of internal combustion engines. This does not include engines as they now are, for engines today have been designed on the theory that something called gasoline will always be available and many who have found objection to alcohol as an internal

combustion motor fuel have failed to take into consideration the increase in efficiency and gain in power which will be possible with a motor designed especially to burn alcohol. Chemical research has already shown its earning power in the production of alcohol from waste materials, and at least two plants of full commercial size have operated successfully with waste sawdust as the raw material. A distinction should be made here between the alcohol made by this process and the alcohol usually derived from wood. The latter should be called not "wood alcohol" but "methanol" a word coined in an effort to eliminate a considerable number of unnecessary deaths due to the internal use of wood alcohol. Methanol is produced by distillation of wood without free access of air, while ethyl alcohol, or grain alcohol, is usually made by the fermentation of some carbohydrate, such as starch or sugar, with subsequent distillation. In passing it may be noted that when grain alcohol is taken into the body it is eventually broken down into carbon dioxide, a harmless gas, and water. When methanol is taken, a poisonous body, formic acid, is produced and death ensues.

It had always been thought necessary to make industrial grain alcohol from materials that could be used for food, that is, some form of starch converted into fermentable sugar by the use of sulphuric acid or by the fermentation of a sugar in molasses. It was a brilliant thing to conceive the idea of converting a part of the cellulose which is the substance of wood into fermentable sugar by the use of acid and heat. Chemically speaking, the molecules which make up cellulose and those which occur in starch and sugars differ by a few atoms of the same materials. They are all made from carbon.

hydrogen, and oxygen, so that the research involved naturally suggested itself. The success of the process is far-reaching. The tropics will always yield large annual crops of cellulose and while, as has been said, an individual might find difficulty in brewing a drink made from the kitchen table leg, it is fair to suppose that some day, thanks to research, the world will be able to grow an annual supply of fuel. We have already reached the stage where it is largely an economic and not a technical problem. When gasoline reaches a price of 40 or 50 cents per gallon, which it may soon do, then ways must be found for the use of industrial alcohol free from tax, which can be produced to sell at from 40 to 50 cents per gallon. So far alcohol and benzol (chemically benzene) in some blend with gasoline, have been the most used compounded liquid fuels. A commercial method for the continuous manufacture of dehydrated or absolute ethyl alcohol at a comparatively low cost has been a great gain. Ordinary alcohol will not mix with gasoline because of moisture, and other compounds like ether must be used to facilitate blending. This is objectionable but with absolute alcohol mixtures in any proportion are possible; 30 per cent alcohol in gasoline has been used with much satisfaction in airplanes while 20 per cent alcohol and 80 per cent gasoline give excellent results in motor cars of the usual design. The magnitude of the problem is indicated by the figures. In 1919 the domestic consumption of gasoline for internal combustion engines was 3,061,000,000 gallons. During the same period only 34,700,000 gallons of alcohol were made while benzol reached a total of 84,000,000 gallons. In 1921 the output of gasoline from petroleum refining, which includes the large amount secured by the scientific

process of "cracking" or breaking down the more complex molecules of petroleum into gasoline, was 5,098,056,-740 gallons. In the same year 473,658,500 gallons were recovered from natural gas known as casinghead gas by absorption, compression and other methods devised by scientists. The production of ethyl alcohol in 1921 is reported as having been 85,068,776 proof gallons, in 1922 79,906,101, and in 1923, 122,402,850 proof gallons. It may well be that research in the future on this important phase of our economic problem will be directed more toward the question of raw materials, which must be abundant and inexpensive. The chemist's part of the program is ready.

RESEARCH AND MOISTURE

Research done on questions where moisture is involved has proved profitable. Consider foods: Milk on the average contains 87½ per cent of water. Its ready spoilage depends to a large extent upon the presence of this water. The transportation problem is rendered more difficult by it. To remove this water without detriment to the nutrition and wholesomeness of the milk has proved difficult. Chemical research has overcome the difficulties. Several processes for drying milk have resulted and one of the most successful is the basis of a plant drying, in the season of flood milk, 70,000 pounds liquid per day. There are many plants of smaller size and the business is remunerative since it permits preparation of milk powders when the raw material is relatively cheap, to be stored and sold when it is more scarce. It also enables people in the tropics, in camps, and on shipboard, to have the milk required. It may well be

considered that dry milk has not yet come into its own but it may be predicted that within twenty-five years it will become as much of a staple as flour and sugar. One of our great cities depends upon nine states for the daily milk supply and five days have been known to elapse between the time the cow was milked and the milk delivered to the ultimate consumer. As population increases it will become more and more difficult to obtain liquid milk in a condition suitable for infants. Even now it is very difficult for many consumers to maintain an ice supply which keeps the milk safe. Furthermore they cannot afford to purchase those grades of milk which are relatively free from bacteria. It seems inevitable that milk must come from greater distances and even if it could be transported and distributed satisfactorily the cost of handling $87\frac{1}{2}$ per cent of water must become a deciding factor. It seems reasonable to suppose that properly dried milk prepared in that quarter of the world where milk can best be produced will be transported and sold as such or reconstituted as liquid milk when required.

Research has found that fats like butter fat become rancid because of a chemical process which goes on slowly even when the milk is dry or in cans. To meet this situation research has shown that other types of fat, notably vegetable fats, like coconut butter, can be incorporated with dry skim milk to make a product of any desired fat content which is wholesome and of high food value. In this way cream may some day be made to order in any part of the world since all the raw materials can be stored for an indefinite period of time. One such plant has been operated to supply raw material for a certain food product and a total investment of less than $10,000

earned upwards of $600 per month. This profit was made by a difference between the cost of making a satisfactory cream and buying natural cream in large quantities on contract.

This compounded cream and milk lack only that food accessory known as vitamin A to make them wholly acceptable as a milk substitute for all classes, especially growing children. The isolation of this vitamin and its preparation on a commercial scale at a low price is one of the things yet to be done. When it is accomplished then it may be added in concentrated form not only to such milk and cream made with vegetable fats but to other wholesome foods from which vitamin A is naturally absent.

Another instance of profitable dehydration is to be found in the case of fruits and vegetables where research has already done enough to show what is possible. The success of dehydrated materials has been greater in Europe than in America, for again, owing to our wonderful resources, our people have not found it necessary to resort to these economies. The difference between dehydration and drying is that ordinary dried materials are more or less leathery because the process has removed the water from the outer layers, and to bring the internal moisture to the surface has involved either high temperatures or long time. When allowed again to take up water the product is unlike fresh material. In dehydration the aim is to remove moisture by osmosis, controlling the percentage of moisture in the surrounding air so that water is drawn from the interior of the material without altering cell structure and before the outer layers are dry. The work cannot be considered completed but research has already shown how to dry such materials as Irish pota-

toes for the dehydration of which there were some 700 plants in Germany prior to the war. It may be that this work will depend for its ultimate profit upon the utilization of cull fruits and vegetables, a considerable quantity of which is now wasted. Our ultimate consumers still insist on perfect products, perfect as to size, form, and color and the grower's problem upon which the aid of research is needed is how to dispose of what is often a large percentage of his crop.

The research on drying and moistening under controlled conditions has been profitable in the tobacco industry, in leather, and in textiles. It was some time ago that it occurred to a manufacturer that the reason he had troubles in his textile mill which were not experienced abroad was due to the absence of fogs and high humidity for which he was thankful excepting in his mill. The slogan of a prominent firm of research men is "Every day a good day," by which is meant that science can now control weather conditions within the plant. There may be a thousand per cent difference in the tensile strength of a dry cotton fiber and one which is moist largely because when dry the sharp twists in the fiber become points of extreme weakness. It is research that has taught us that in the drying process the greatest progress is often made with moist air, provided only that the moisture content of the air is enough below that of the material to be dried to cause the latter to give up some of its water to reach a stage of equilibrium with the surrounding air.

While discussing moisture it may be well to point out that chemical research has saved many a manufacturer several good dollars by showing him how to avoid buying water. There is the instance of one of the large users of

alum who found a saving of $108,000 in a single year after a chemist had showed him that he was buying a large percentage of water with his alum. So great is the temptation to sell water that it is one of the first considerations in many commercial transactions. It has been responsible for research on the conditioning of silk, by which is meant the determination of the weight of raw silk on a dry basis after which allowance is made for the moisture it would take up under normal conditions. Limits have been set for the water content of butter and for many items which absorb moisture much more readily.

In 1920 about ten million pounds of artificial silk were made in the United States. This rose to twenty million in 1921, twenty-six in 1922 and to thirty-three or four millions for 1923. The output must soon be rated in tons and car loads. The whole business is a chemical business founded of course upon research. There are several types of artificial silk but those most in vogue are made from the cellulose to be found either in wood or in cotton. The cellulose is first purified and then in solution forced through exceedingly small orifices. The extruded material goes into a setting bath which consists of a liquid in which the dissolved cellulose is insoluble. The resulting tiny, long tubes are combined to make the thread which is then washed or otherwise purified and prepared for the market. Artificial silk now so universally used has had a hard struggle. The technical difficulties to be overcome are very real and numerous. Research has had to be constantly employed and no less than three companies formed by the original inventor failed before the fourth made an unprecedented success. Much fundamental research on the structure of the cellu-

lose molecule must be done before some of the present manufacturing difficulties can be effectively overcome.

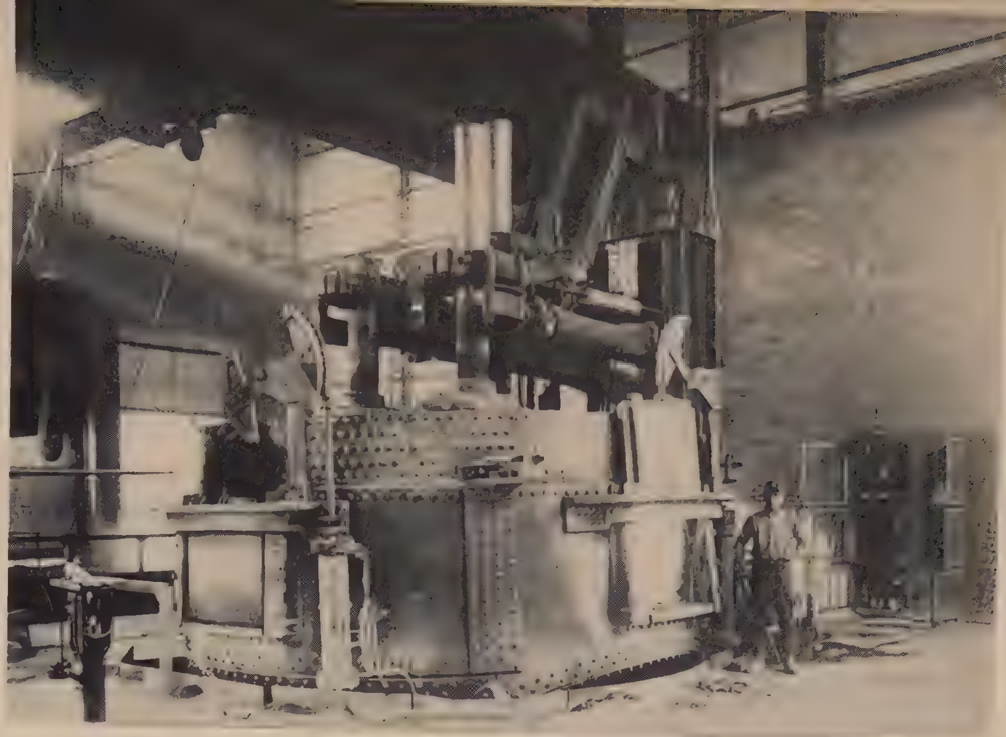
In normal times about $50 is added to the value of every bale of cotton grown in the United States as a result of the chemical research that has been applied to cotton and cottonseed products. Time was when cottonseed was thrown into the streams of the South to get it out of the way and one state actually passed laws prohibiting dumping of seed in the streams. Then came chemistry which took the seed and found ways to produce oil, meal for stock feed, and fertilizer, while with the help of the engineer cotton fiber was salvaged from the seed in great quantity. Something like 700 mills are now interested in vegetable seed crushing. When the passing of the war took away a large part of the market for these short fibers used in the preparation of explosives, the research chemist once more came to the aid of the industry and found a way to make high-grade pulp for writing paper from this same cotton fiber.

The application of paper in many new fields and the production of fiber board furnish additional illustrations of research in commerce. Spectacular use of paper has been much discussed of late years following the announcement that by forming threads from paper, cloth could be woven, and that such cloth was in use in European countries. Samples of this cloth are surprising in their softness and resistance to washing, owing to chemical treatment of the paper, and it is used in a variety of places especially substituting for the cheaper coarse fibers. Here we see this same type of material, though woven differently, utilized for onion bags.

Another spectacular use is in the production of sugar cane in Hawaii. One of the plantations failed to make

money because of the excessive cost of removing weeds which grew luxuriantly under tropical conditions in the deep rich soil. The Yankee manager of the estate undertook to find ways to kill the weeds by methods other than hoeing, and after experimenting with sprays and many other methods thought of paper. A soft asphalted paper was found strong enough to resist handling and the weather for six weeks and yet was so formed that the sharp strong cane shoots could penetrate it. A large-scale experiment proved that this paper when laid over the cane row could be held in place with stones and field litter long enough to allow the cane to gain great headway over the weeds, thus reducing cultivation to the space between the rows, which is easily done with horses. The cane shoots which failed to penetrate the paper were released after a short time by cutting a slit in the paper. This was quickly accomplished with a machete. The result was a saving of from 50 to 70 per cent in the cost of growing the crop while an increased yield of sugar cane of ten tons per acre was obtained. This is equal to about one ton of raw sugar. The conditions under the paper were such as to encourage the rapid growth of the cane, likewise of the weeds, but the weeds being soft-topped could not penetrate the paper and were blanched and soon died. The result was an unusually clean field of cane grown at a substantial profit. Research pays.

A single chemical fact is the basis of the photographic industry in which the capitalization of a single concern is $35,000,000. Silver chloride is turned black by the action of light. That is the phenomenon with which research began. To be sure the manufacturer of sensitized film, plates, and paper requires continual research and chemical control, but this affords an illustration of



A twenty ton, three phase Héroult arc furnace. Carnegie Steel Company, Duquesne, Pennsylvania.

what applied science can build up. The Welsbach mantle is not only the foundation of a very prosperous business enterprise but has been the savior of the gas lighting industry. Until very lately there were some states where the value of gas was still rated on its candle or lighting power, though certainly 95 per cent of such gas is used because of its heating power. With the advent of electricity as a lighting medium the future looked dark for gas lighting, but research came to its aid. Ways were devised for holding the mixed oxides of thorium and cerium in the form of a mantle which when heated becomes incandescent and glows, giving off light which is at once pleasing and efficient. It is the mixture of these oxides which gives the color of light desired. The manufacturing operation requires chemical control and great care, but the profitable results fully warrant it.

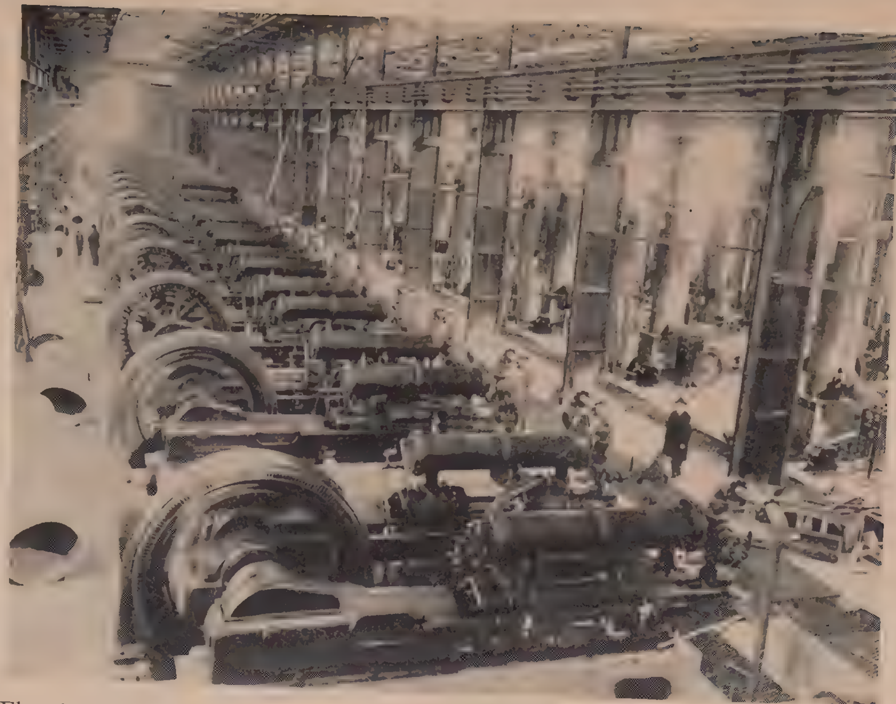
In the last analysis most industries are founded upon scientific achievements, and since the chemist is largely concerned with changing substances found in nature so as to adapt them to men's real needs, some instances of the creation of new industries because of chemical achievements may serve to illustrate the point. When Mercer discovered that, when cotton fiber is immersed in a sodium hydroxide or caustic soda solution of a definite strength under tension, its characteristics are changed, he laid the foundation for the process now known as the mercerization of cotton. This is a chemical process which tends to straighten the cotton fibers and thus strengthen them. At the same time they are made so smooth as to impart to the cloth a more uniform and consequently a more highly reflecting surface. Properly mercerized cotton, therefore, has a luster, which is greatly desired, as well as increased strength.

CHAPTER VI

PROFIT EARNING RESEARCH

H. E. Howe

The case of indigo has become a classic. It illustrates the profit earned by adequately supported research, continued under capable direction in the face of great difficulties and high costs. It has been said that 29,000,000 gold marks and five years of time were required for the development of the process which led to synthetic indigo. When it is remembered that perhaps 60 per cent of the cloth dyed in the world is dyed black or blue and that the shades obtained with indigo are perhaps the most popular and useful, the importance of the synthesis becomes apparent. Our recent experience in perfecting the manufacture of synthetic indigo in our American factories is sufficiently vivid to require no further emphasis. The completion of the process is said to have been due to an accident, the significance of which was not realized until an investigation was made. A research chemist repeated the final step of the theoretical process, although the experiment had been made many times before without success. On this occasion he obtained the much-sought intermediate compound and in the questioning that followed regarding the temperature to which the mixture had been heated, he confessed that he had broken an expensive thermometer. It proved to be the mercury thus liberated that was required in the reaction chamber to produce the desired results. The



Electrically driven air compressors for the production of liquid air. United States Air Nitrates Corporation, Muscle Shoals, Alabama.

investment in this research has since proved to be one of the best ever made in industry.

The alloy of chromium, cobalt, and tungsten, first made in an experimental way, has proved in late years to be one of our most important alloys for high speed machine work. Its production in various forms has become a separate industry, yielding a profit of many thousands of dollars per year because this particular alloy will work at white heat and retain a cutting edge. Where deep cuts are to be made at high speed there is no competing material and, while it is not satisfactory for some types of tools, it played a most important part in war work. The use of such an alloy or the more familiar tungsten steel means that a given equipment formerly using high carbon tools can be made to produce three times as much work with the same amount of labor, merely because the cutting tools can be operated at three times the speed. Indeed, a somewhat greater speed can be maintained with the cobalt-chromium-tungsten material. Incidentally, it resists the attack of organic acids and consequently remains bright when used in a variety of cutlery.

In another field illustrating the same point lie casein and its many products. Casein is obtained from skim milk, so long a waste from creameries and dairy operations. Its preparation by acid treatment of the milk is comparatively simple, and here and there small units have been established for its manufacture. It is a useful product and finds application particularly in a type of glue greatly preferred in a variety of operations. It also forms one of the constituents of ivory substitutes and in this form has made its appearance in billiard balls, umbrella handles, knife handles and the like.

When the development of great quantities of hydro-

electric power at Niagara Falls was first conceived, it was the hope of the promoters that, because of cheap power, many looms, lathes and other power-consuming machinery might be attracted to the site and a great mechanical industrial center built up as a result. An industrial center has resulted, but it is of an entirely different character than had been anticipated. The present industries at Niagara are based upon out-and-out chemical reactions involving such common substances as lime, coal, air, sand, salt, and alumina. These industries have created great wealth and have, indeed, placed the country under obligations, for in many respects they are key industries. There are many places where natural graphite cannot be used successfully because of the large homogeneous pieces required. These are obtainable only from artificial graphite—the product of the electric furnace and the art of the electrochemist. Indeed, the electrical industry of today, with all that that involves, depends upon the perfection of artificial graphite. The real value of research involved is difficult to estimate, for wherever electricity is employed and electrolytic apparatus installed, there you will find some form of artificial graphite. Electrodes used in electric steel furnaces are often nearly as large as a man.

Abrasives also result from these processes. They involve sand, alumina, carbon in the form of coal, etc. They provide almost 100 per cent of the abrasive material used in our country today. They are produced with a greater constancy of physical characteristics than can be found among natural abrasives. They are harder, they cut faster, they can be produced with grains of a given size and so are much more convenient and better suited to the majority of uses than are the natural abrasives.

Thanks to the research of the ceramic chemist, ways have been found to take these various cutting agents and, in combination with clay and binders, to perfect sizes, shapes, and grades of cutting, grinding, or polishing tools with which greatly reduced labor costs in the finishing of many an intricate part are possible.

When one day a keen experimenter chanced to throw a mass resulting from an experiment wherein lime and coal had been fused in an electric furnace, into a pool of water standing after a recent rain, the great calcium carbide industry was born. This experimenter saw the bubbles from the lump that sank beneath the water. A further investigation and repetition of the experiment proved to him that the gas was acetylene. Today the industrial organization, which has the roots of its prosperity reaching back to that simple experiment, is rated at many millions of dollars, and nearly everywhere calcium carbide and the acetylene gas which results when it is treated with water are well known. It has been research which is responsible for maintaining a demand for carbide long after its use in bicycle lamps has become a thing of the past. It was research that found a way to store the acetylene gas from carbide compressed in little copper tanks which used to be a familiar accessory of every automobile and, while the electric headlight has now replaced it, the tanks of acetylene gas are everywhere in still more important use. The oxyacetylene flame produces heat that will quickly cut through great masses of metal. It has also been used to heat to incandescence, lime and magnesia in certain types of signal apparatus where intense light is necessary. It is a starting point in the synthesis of acetic acid and from it carbon black can be made to supplement the supply now made from natural gas. It

is the source of light in gas buoys and in highway lighthouses. It will be research that will continue to find applications for this industrial gas made by a chemical process and widen its field of usefulness.

Carbide itself offers one method for the fixation of atmospheric nitrogen, now an important subject of everyday discussion. When the molten carbide is allowed to come into contact with nitrogen it fixes a certain percentage of that gas in a form that makes it easily available under conditions which the chemist has determined. Until recent years this was the one method for nitrogen fixation, save only the arc process which operates with such low efficiency as to make it economically possible only in such countries as Norway where power is generated at an unbelievably low figure. It was through calcium carbide that Germany fixed atmospheric nitrogen prior to Haber's experiments and it was this process upon which the great plant at Muscle Shoals was erected during the war. It now seems certain that the research on that type of method with which Haber's name is so prominently connected, will lead to the establishment of another great industry in this country. Its extent in Europe is already such as to command a large home market and turn the sale of nitrates made in Norway toward this country, the price competing with that of the natural Chilean nitrates. Indeed, there is one commercial unit now in daily operation in the United States and, because research was continued even after that plant was designed, the operators were surprised to find much lower cost possible than they had anticipated, as well as a substantial increase in production. This was due largely to successes attending the development of the catalyst, which is responsible for the union of those inactive gases,

nitrogen and hydrogen, under certain conditions of temperature and pressure. However, so long as great temperatures and pressures are required, research must be continued, for until the fixation process can be made to go forward with a lower consumption of energy, the problem will not really be solved. In France the line of attack is in the direction of higher pressures, the experiments there being conducted under a pressure of a thousand atmospheres. A few years ago this would have been thought impossible, but by working in small apparatus, commercial units have been installed which give no difficulty. It has been found that the increased yields obtained, the greater ease in drawing off the liquid ammonia from the gas mixture, and the lower temperatures required, make the higher pressure something of a real economy. One needs but remember our requirements of nitrogen for fertilizer purposes, which will undoubtedly increase as we continue year by year to harvest the nitrogen now in the soil in the form of crops, to conceive of the vastness of this industry yet to be developed. Add to this demand the requirements for manufacturing purposes and its importance will be realized.

FROM MUSEUM TO COMMERCE

Many can easily remember when aluminum was simply a laboratory curiosity valued at more than fifty dollars a pound. Chemists knew that aluminum existed in great quantities in many clays and ores and the high price of the metal was simply due to difficulty in obtaining it from the material in which it was found. Persistent research carried on independently in France and America resulted in the almost simultaneous discovery that the

ore called bauxite when dissolved in a molten bath of cryolite can be electrolyzed and the metal aluminum obtained. With that beginning, the commercialization of the process has made aluminum one of our common metals, the production exceeding 100,000,000 pounds per annum. The problem has become, not how to obtain aluminum, although we still have to learn how to separate it economically from some clays, but how best to use aluminum in the arts. Where lightness is desirable but where greater strength than that possessed by aluminum alone is essential, a series of bronzes and other alloys involving aluminum magnesium and copper have been developed through research.

The success attending experiments on aluminum have led others to investigate metals, such as magnesium, which until recently had hardly been considered metal in the commercial sense. The necessity for providing large quantities of magnesium metal in powdered form for star bombs and illuminating purposes, led to the production of magnesium in sufficient quantities to justify research looking to other commercial applications. It was found that with traces of copper and other metallic elements sound castings of great strength could be made and these find application in air craft and more recently in certain parts of automotive engines, such as pistons.

Working with the metallurgist and electrical engineer, chemical research has built up another industry generally designated as ferro-alloys. There are a great number of alloys consisting principally of iron with which rarer elements, molybdenum, chromium, silicon and vanadium are alloyed. These are best made in electric furnaces in which more accurate control, both quantitative and qualitative, can be obtained. These alloys in

turn have the greatest industrial significance. Ferro-chromium is essential to armorplate; ferro-silicon makes possible steel by the open hearth process; and ferro-vanadium produces the steel which has made the low price of automobiles possible. This is not because of the greater strength which this type of steel possesses, but because it is as strong as high-carbon steel which would have been used for strength but which is not machineable. The vanadium steel is machineable and the difference in cost between machining and grinding a high-carbon steel gives a finished part at one-third the cost, notwithstanding the difference in cost of the raw material.

Chemical research plays a vital part in the improvement of processes and the lowering of costs. This may be done by reducing the number of rejected parts after finishing, or by finding raw materials at a lower cost, or by the utilization of factory wastes. Physical testing and chemical control by the analysis of raw materials are other important features. Management engineers, often called in to improve factory conditions, have come to know that chemical control is their greatest ally. It is quite impossible to standardize upon a proper day's work unless the workman is to be provided with standardized raw materials, tools, and controlled processes. These are not possible without standardizing raw materials. There have been many tons of glass manufactured at high cost, only to be thrown on the dump heap because the plant superintendent refused to recognize the importance of the chemist in analyzing the batch so that color components might be kept at a minimum, or might more completely neutralize each other. Manganese, used in some types of glass to reduce the green color, due to

iron, by changing the iron to one of its own colorless compounds, will produce an amethyst color or even violet if used in excess. It requires the chemist to determine the proper amount of this so-called decolorizer. Chemical control lies at the very basis of good steel-making and some of the most rapid analytical work has been developed because the furnaces were often held awaiting reports as to the analysis of the contents. No sugar refinery can operate successfully without chemical control, and quantities of sugar up to 500 barrels have been known to revert or change to glucose-like material because accurate control was not being maintained.

During the war when high prices for potash made its recovery from a certain type of southern felspar an economic procedure, a small plant, utilizing a rotary cement kiln in which to heat its mixture, had a weekly analysis made at a cost of fifteen dollars each. The resulting burned material possessed a certain amount of soluble potash salt and when reduced to a powder could be used in its entirety, since the balance of the material played the part of the filler in the fertilizer. The product was sold on a guaranteed soluble potash basis. When for some time the material happened to run uniform, the plant manager concluded he was wasting his money on chemical analyses and discontinued his arrangements with the consulting laboratory. It took him just two weeks to ship enough unsatisfactory material to bankrupt him and close the plant. He undoubtedly believes in chemical control today.

Heat treatment has become an art capable of producing wonderful results in metals where the rate of cooling and the temperature drop during the operation is used to control the grain size in the metal and the

structure of the mass. If uncontrolled this treatment can easily lead to all sorts of difficulties, but it took a long time for plant managers to realize that the recording pyrometer is far more dependable than the eye of the most experienced workman. It has taken some time also for them to realize that the pyrometer itself needs the watchful eye of the chemist-metallurgist who understands what is to be accomplished and also the inherent weaknesses of recording instruments. An example is that of a New England manufacturer who was making small metal parts for the Government. These parts had to be shaped accurately and then hardened. If the hardening process were not properly conducted, twists in the parts resulted and for this reason rejections at one time exceeded 75 per cent of the output. The chemist was then given his opportunity and not only determined the proper method of heat treatment but found that the pyrometer in use was inaccurate. A few days' work brought the percentage of accepted finished material to above 95 per cent where it was maintained throughout the contract. He distanced all competitors.

The celluloid industry in all its ramifications depends upon the part camphor plays in the compound. Until recent years camphor has been obtained only in the Far East, where one country maintains a practical monopoly. Three lines of work have been followed out to free the manufacturers from this monopoly. Research specialists in the plant sciences have established camphor-bearing trees in our own southland and the research chemist has developed more than a hundred possible substitutes for camphor. At least two or three of these have been found satisfactory in many instances. The research chemist has also developed synthetic camphor in the laboratory

and this industry shows promise. Synthetic camphor can be made in the United States from spirits of turpentine, and a corporation has recently offered to extend its plant to be capable of producing 2,000,000 pounds per year for the benefit of the celluloid industry and the artificial and patent leather manufacturers, who now use about 5,000,000 pounds of camphor annually.

A certain New England textile mill had been in the habit of buying 1¼-inch cotton fiber for one of its staple products. A research chemist found that the finished produce showed a fiber of 1⅛ inches in length and going back over the process found a point where the machines were so set as to break off this missing ⅛ inch. The fabric was satisfactory and he therefore proved that if the machinery was set so as not to damage the fiber, cotton 1⅛ inches in length could be satisfactorily utilized without detriment to the finished product. A substantial saving could be effected, for when fibers exceed an inch in length there is an increase in price for every slight increase in length. At one time a few years ago fibers 1¾ inches in length sold for as much as $1.20 per pound in the New England market.

TIME FACTORS

Time is one of the most valuable things which the manufacturer has to consider. The research chemist frequently finds how to conserve this element. At one time it was thought that a certain bleaching operation required thirty-six hours for its completion. When a chemist was put on the job, he found that under controlled conditions of temperature the reaction could be satisfactorily completed in forty-five seconds without

damage to the fabric. The mill is a large one and difference in the cost of necessary equipment, interest on the value of goods in work, and the quantities of bleaching agents required meant thousands of dollars.

In another mill, a thousand looms stood idle because of difficulties beyond the reach of experienced operators. Again the chemist was called in. He found that the frequent breakages occurring in the threads being woven were due to chemical reactions arising from imperfect dyeing and from the employment of sizing materials not suited for the purpose. In three days he had found the trouble, eliminated the causes, and enabled the looms to take up their ceaseless clatter.

Few things are more essential to industry than proper lubrication. This fact holds whether it is a drop of oil on the sewing machine or washing machine or the one hundred gallons a day that would be used in a large hydroelectric power plant. The fact that oils other than petroleum have not been found satisfactory constitutes one of the dangers arising from burning petroleum under boilers today. We preach much of the necessity of developing hydroelectric power plants and yet a plant of a half million horse power or any other capacity must close down if it cannot be properly lubricated. There are other types of lubrication than oils which the research chemist has just begun to develop. The soft bearing metals have long been known and a great deal of experiment conducted relative to the proper hardness of these alloys and the best method of using them in place. Of late advance has been made by using graphite so imbedded in the metal as to make it well-nigh self-lubricating. At the same time it is porous enough to permit efficient oiling from without. This

unusual bearing metal is made by mixing the oxides of the metals with sufficient graphite to reduce them, when heated, to the metallic state and yet leave sufficient graphite to assist in the lubrication. When pressed into form these units are sintered and then turned into shape. The research employed in this case is sure to prove an unusual investment since proper lubrication means power, and power can always be discussed in terms of fuel costs. The importance of power saving can hardly be overemphasized so that research of the character described becomes an earning agency not only for those engaged in the manufacture of the bearing metal but for the users as well. The research has given us ball bearings, roller bearings, direct driven machines, and shaft hangars with improved bearings which have all played a part.

The speeding up of processes through chemical research is illustrated by the employment of an inert substance in the process of filtration. Many substances to be filtered leave a slimy deposit upon the cloths and other filtering mediums used on filter presses, greatly reducing the rate at which liquids can be put through. Typical difficulties are imperfect clarification, which means refiltration and loss of liquid because of incomplete washing. Research has demonstrated that kieselguhr, which includes both diatomaceous and infusorial earths, when properly prepared and added in suitable quantities overcomes these various troubles in many instances. This has been true, for example, in the refining of vegetable oils, in the cereal beverage industry, in the soap industry, and in handling fruit juices. Complete separation of solids from liquids is thus obtained without effecting chemical changes, and labor-saving types of filters have

been found satisfactory with a decreased cost and increased quantity which has meant many dollars to the manufacturer. In one operation with cereal beverages, a net saving of 8½ per cent per barrel was realized by the simple procedure of using one-half pound of the kieselguhr per barrel.

In the great rubber industry, research of late has been profitably directed along two principal lines. One of these has been the saving of time in effecting satisfactory vulcanization. The older process required heat and pressure for about two hours. About 1910 or 1912, research chemists began to find that this process could be accelerated if the vulcanizing was carried on in the presence of some one of a number of organic chemical compounds, prominent among which was aniline. The development of these accelerators, some of which enable satisfactory vulcanizing in from one-quarter to one-fifth of the time for the old process, has not been without difficult problems. There have been factors of safety to operatives and peculiar effects upon fabrics to be worked out. There are two interesting examples of the latter which might be cited. In one large warehouse, case after case of finished cotton goods was found discolored with various tints. Some of these goods had been sent out without unpacking and of course gave rise to complaints. The boxes were just as they had been received from the finishing mills and the goods besides being individually wrapped were in cases that were paper lined. A research chemist undertook the problem, which became serious in a short time, and noticed that those goods which were adjacent to certain large stocks of rubber tires and tubes were the most likely to be affected. He soon satisfied himself that it was the action of the organic

compounds used in accelerating the vulcanization process that was responsible. A rearrangement of stored material proved effective. The other case is very similar and had to do with rubber-soled shoes. The white tops turned pink in this instance, also owing to the action of an organic accelerator.

Another development has been in the line of adding wear to the compounds making up the tread of automobile tires. We do not yet quite understand the action of some of the fillers used but good results have been obtained with materials like carbon black, which some believe serves to postpone that oxidation of the rubber which leads to brittleness, cracking and a loss of toughness which means early failure under conditions of wear. Others contend that it is merely the particle size of the filler which counts and offer a specially prepared zinc oxide of extreme fineness in place of carbon black. The public now using something over 10,000,000 automobiles will benefit most in this research, the value of which must be continually measured in the millions of better tires and tubes. The results have already been experienced in the form of deferred purchases of tires because of increased wear in those now obtainable. The textile chemist has had his part in the work, for improvements in fiber and cord have given added strength to carry the load over rough places and support the wearing rubber surface.

Many an office is grateful for the time saved by the use of the so-called window envelopes. Many such envelopes are made by fastening in proper place a piece of paper treated with a compound to make it transparent. The handling necessary in this method of manufacture adds somewhat to the cost of the product which has often

caused trouble in the mails. It was a research chemist who evolved the method of applying the compound responsible for the transparency of the paper, directly to the envelope by a printing process. Simplification in the production of an article used in such quantities is apparent.

The attention of research men was directed with emphasis to charcoals and carbon during the last few years when absorption mediums for gas masks were so much in demand. It is but natural that this research effort should have been turned to the employment of these charcoals with unusual physical properties as decolorizing materials. This is a very important matter, especially in the sugar industry. We prefer sugar so white that not so many years ago it was the practice to blue granulated sugar with ultramarine, just as bluing of one composition or another is used to whiten clothes because it neutralizes the natural cream shade of the fabric. If the syrups and juices boiled for the crystallization of sugar are very white and brilliant the resulting sugar will be white, and various charcoals have been employed to absorb those bodies which are accountable for the color. Charcoal from bones, known as bone-char, has been long used for this. Superior charcoal is made under the guidance of the research chemist from such material as peat, lignite, rice hulls, kelp, and corncobs. These absorbing chars are also applied in the petroleum industry.

Another modern method, which is effecting a saving for all through lessened cost, is spot welding, where the electrical engineer has done research of a profit-making kind. The thin sheet-metal containers and devices, now so common, would be prohibitive in price if all the joints

and points of contact required soldering as of old. In the textile industry particularly important savings have been achieved by substituting in machinery stamped and formed sheet-metal parts for the much heavier castings. Many such parts require spot welding. By various designs of electrodes, the size and shape of the welded spot is controlled and thin metal put up with a strength that could not be obtained by any of the older methods.

In the field of satisfactory substitutes artificial leathers must be listed well toward the front. Literally millions of yards of fabric treated to render the service of leather are to be found on furniture, automobile upholstery and in a variety of everyday uses which speaks well of its adaptability and satisfactory service. It is interesting to note in passing that most of these leathers consist of a chemical compound with cotton as a base spread upon a cotton fabric; dyes, developed in the laboratory add variety; and flexibility is obtained through the arts of research. Another covering which can be considered a substitute is linoleum, where a large mesh fabric serves to carry a mixture based upon the results of research. Oils, particularly linseed oil, as the name indicates, serve as a binder for the variety of fillers used, chief among which are cork and wood flour. Research still has before it the possibility of using other types of fillers now known only as industrial waste.

There is something so satisfactory about beautiful leather as a covering that the public seems to prefer it wherever it is suitable. It is not easy to put leather upon metals in a manner that will continue to give satisfaction. This led research to devise a way of vulcanizing rubber directly upon metal and at the same time give it the appearance of leather. This has been cleverly

accomplished by making an electrotype from a handsome piece of leather, etching the plate rather deeply, and using it to impress soft rubber. The rubber is then cut and fitted to the prepared metal surface, and vulcanized in place. Lacquering follows and an article having the appearance of leather and yet superior for this purpose is the result. The process is cheaper and in every way better than the older method.

Who will say what research work in perfecting the thermit process for welding and casting has earned upon the original investment! The thermit process has proved to be not only a substitute for some types of welding and molding but a satisfactory process for the preparation of very pure metals. It is based upon a chemical reaction in which metallic aluminum is used to take up oxygen from the metallic oxides employed, the heat produced meanwhile being sufficient to melt the mass almost immediately and give rise to a stream of unusually pure metal. Where breakages require that large masses of metal be supplied to effect repairs, this process has proved a time and money saver on frequent occasions. Immense crank-shafts and parts of machines have been repaired practically in place, so that this device of the scientists was most useful and effective in repairing ships damaged in American ports in 1917.

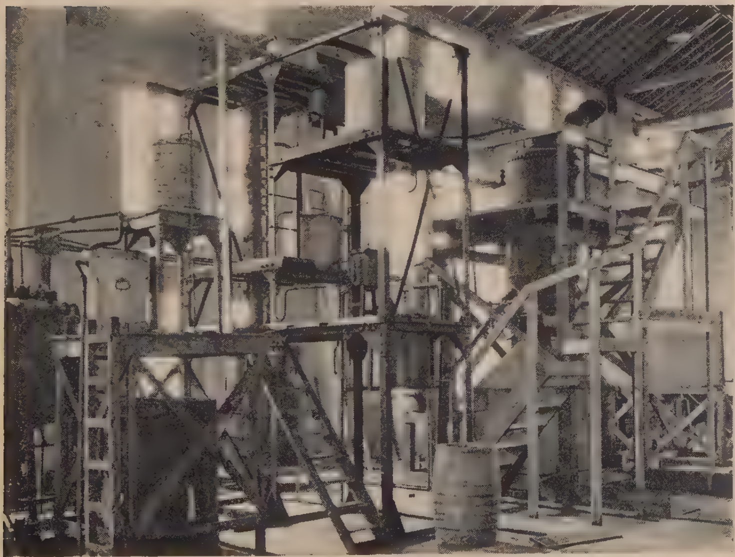
EXAMPLES FROM STUDIES ON WASTE

Many pages could be written on the elimination of waste in industry accomplished by various sciences. It was some years before we knew the optimum conditions for efficient boiler room practice, and many manufacturers even now refuse to apply science in the control of fuel

purchases and uses. Stack temperatures, percentage of carbon dioxide, and other vital factors have been studied and standardized. Science has even gone to the extent of providing automatic recording apparatus, which tells hour by hour how efficiently the fuel is being used. In one plant a scientist once offered to reduce the fuel bill 20 per cent if permitted to put into effect certain procedure which is now well established. In those days coal was somewhat cheaper than it is now and the manufacturer was little interested. Said he, "Suppose you do save 20 per cent of our fuel bill; that would only be $100,000 a year. If you will show us how to save 2 per cent of our raw materials bill we will be glad to give you a contract." The light bill of an establishment was reduced some 30 per cent by adopting the suggestions of an illuminating engineer who studied their requirements and made practical suggestions. In another instance the chemical engineer saved nineteen tons of paper pulp per day by the simple device of placing screens on the sewers, and in a different industry a saving of $5000 a year was made when a chemist pointed out that a certain waste regarded and familiarly known as mud was in reality silver from the mirror room. It was not silver in color merely because of its physical state.

In the manufacture of paper pulp by the sulphate process, which pulp is used for kraft wrapping paper, a large item is the recovery of soda. This involves the evaporation of waste liquors which are wont to foam so intensely as to make it impossible to handle them by the usual evaporator process. The chemical engineer conceived the idea of utilizing the wood lignin, present in large quantities in this waste liquor, as a fuel, and obtaining the soda as the carbonate or sulphide. He de-

An industry founded on a chemical reaction. Eastman Kodak Company, Rochester, New York.



Furfural from corn cobs. An experimental plant of the Bureau of Chemistry, Department of Agriculture.

signed an entirely original form of apparatus and succeeded in evaporating this liquor to a somewhat syrupy condition. This is sprayed into combustion chambers and burned beneath the boilers. In addition to the heat units required to evaporate the waste liquor there is a surplus of some 1600 horsepower per day, the recovery of the soda is wonderfully simplified, the percentage recovered is increased, quality is improved and the labor of many men is saved.

Whole groups of new industries have been built up on the wastes existing in older industries and not infrequently these newer activities surpass in importance the parent ones.

Many examples of worth-while research can be drawn from the field of biology, and the plant sciences in particular. It was research that was responsible for the introduction and establishment of particular varieties of wheat adapted to certain climatic and soil conditions in the United States. It is true that some of these varieties were accepted with great reluctance by the millers, but time has proved that these varieties are of economic importance, particularly to the manufacturers of macaroni, and that this wheat is a worthwhile factor in the export business. It cannot be considered that this work is by any means complete, for we still need better drought-resisting wheats, wheats that will withstand the winter climate of many of our wheat states, and varieties which can be grown satisfactorily in limited areas where soil, waterfall and temperature conditions form an abnormal combination. Indeed, the intellect responsible for the breeding of our modern food grains from the wild plants of prehistoric days was of unusually high order, and the work in those times went forward with such

rapidity that we are not certain as to the original plants from which the present grain-bearing ones have sprung. Incidentally, the domestication of the horse, cow, and dog was an achievement of equally high order.

It was research that was responsible for the production of more leaves on the tobacco plants in Connecticut. With the same amount of labor in raising the crop the addition of some 30 to 50 per cent in the number suitable for cigar wrappers is no mean item of revenue for the grower. It is only by research that diseases which threaten tobacco crops can be combatted successfully. Much has been done in something more than a preliminary way in developing plants with greater disease resistance, and at the University of Wisconsin new strains have been raised which are far more resistant to root rot than the current varieties. The sterilization of tobacco seed beds has also been of immense value in supplying healthy plants for the fields, and without research this could not have been accomplished for it was first necessary to learn something of the factors concerned and the troubles to overcome. When it is recalled that in normal times an acre of tent-grown tobacco represents an investment of $1000 up to a time just after the plants are set out, the importance of protecting this investment is apparent. Some companies have lost 60 acres in a single season because of diseases not as yet understood but upon which research men are active.

The economics of research in horticulture are illustrated on the Pacific Coast where hybridizing has given a variety of English walnut which grows with the rapidity of the common poplar tree and therefore comes into bearing years before the original English walnut.

The development of new types of melons has proven

a profitable enterprise and has not been accidental. Scientists and experienced growers working together have set out to accomplish a given purpose. The improvement in sugar content and purity of sugar juices extracted from beets affords further illustration. When France found it necessary to consider new sources for sugar, when imports were cut down during the Napoleonic wars, she turned to sugar beets. At that time the beets were small, the water extract contained a high percentage of impurities, and the sugar content has said to have been below 6 per cent. It has not been an easy matter to reach the present high sugar content and degree of purity, but it has been possible by the careful application of this type of research. Beets today may average 18 per cent sugar through thousands of tons and in many cases approach 30 per cent with a purity quite satisfactory from a manufacturer's standpoint. The grower as well as the manufacturer has benefited from this research, for in nearly every beet-growing community the price bears a direct relation to sugar content. Likewise the starch content of the potato has been wonderfully increased and in Germany the tuber has become an industrial raw material produced for starch alone. In our country a somewhat similar line of work has shown that corn can be produced with high oil, protein or starch content as may be advantageous for its ultimate use. It is reasonable to believe that research will add many dollars to the income of cotton growers when one of these days we undertake to grow cotton with the optimum yield of commercial fiber in combination with high oil-bearing seed.

Forest products, in addition to their usefulness as raw materials in various economic operations, have been

made more valuable and have also been conserved through the application of various types of science.

Until research established the physical constants for structural timbers there was a considerable loss due to using timbers much larger than necessary for the sake of being sure of ample strength. The safety factor was much larger than necessary and this was economically important with the gradual disappearance of those timbers of large cross section which used to be so prevalent. Research has now taken up a problem which may be considered the opposite extreme, namely, methods for utilizing small pieces of wood involving laminated and built-up pieces made strong enough to take the place of larger boards and structural members. While glued material of this kind would not be recommended for some types of building, still there are many applications for material of this description. Its ultimate success will depend on the adhesives and methods for their use. For this we must look to research. Veneer manufacturers and others utilizing adhesives in quantities have had occasion to be thankful for the new types already developed in the course of this investigation. Cheap adhesives have also been produced, especially from corncobs, and before long this may become a worth-while factor.

These are illustrations from a field of waste utilization and in such a discussion the electrolytic methods for dust precipitation that have already proved a wonderful economy for the industries, must be noted. This process, known as the Cottrell process, is based upon the electrification of the small particles that make up dust, smokes, and fumes, with a charge that is attracted by its opposite on the electrodes. This causes the electrified par-

ticles to fly to the electrodes from which they are removed by various methods. The work was begun in a successful effort to free the atmosphere from sulphuric acid fumes incident to chemical manufacture. It has since been applied in a variety of industries, for the abatement of smoke and smelter fumes. Dollars and cents achievements are credited to this process. In addition to its ability thus to save wastes and avoid losses the principle has been applied to manufacturing processes for the gathering of dusts which are the principal product as in some drying operations. Enough potash was gathered by this process in one cement mill during the war to pay all operating costs, dividends, and interest charges for the entire plant.

When zinc was in demand for munition purposes, research made it possible to use complex ores from which zinc was recovered by an electrolytic process. These ores were not suitable for other types of treatment and the method developed then continues in use in several localities. The electrolytic method of transferring and depositing metals has also had economic application in the preparation of plates for engravings. In one of the government laboratories it was found that, by making certain alterations in the electroplating bath and by proper control of the electromotive force employed, a plate can be built up with a surface so hard as to make it possible to supersede expensive engraved steel plates. Plating has been used with much profit in building up metal parts to required dimensions. In many cases where plating is used to give a base metal or alloy a veneer of a more precious metal, the product is more resistant to wear and corrosion than the precious metal which it simulates.

Much has been lost in industry because of the failure

to recognize the importance of minerals dissolved in water. It is only recently that we have begun to discuss "zero water." This expression is used to designate water from which the calcium, magnesium and other hardness-producing salts have been completely removed. The presence of mere traces of some of these materials makes even dyeing difficult if not impossible, interferes with industrial processes involving chemical reactions, and, where soap is employed, necessitates the waste of large quantities. When soap is added to water of this kind the fatty acids which form the basis of soap are broken away from the sodium or potassium, with which they are combined, and form a new compound with calcium and magnesium. These compounds have no cleansing properties but use up serviceable soap in their formation with the production of an inconvenient and ugly scum on the water. If this is not rinsed from cloth it leaves a gray color due to its deposition in the meshes of the fabric. Today with very efficient chemical water-softening processes available it is hard to understand why some textile mills continue to use hard water, for the losses are constant, are considerable in the aggregate, and, as has been said, are preventable.

CHAPTER VII

THE WASTE PROBLEM. METHODS OF PROCEDURE TOWARD RESEARCH

H. E. Howe

The utilization of wastes is seldom an easy problem, notwithstanding the examples where the character of the material almost automatically suggests a diversity of uses. Thus, pith and certain grades of waste wood can be used as fillers in plastic material and the wood flour industry has grown up from such experiments. The nature of some compounds naturally limits their usefulness and we have in mind tellurium, an element recovered as a by-product in the refining of copper. Selenium is also recovered under the same conditions and both elements, for a long while, had been practically useless. Selenium was the first to be put to work when it was found that it was useful in the manufacture of glass and could be employed to produce a better red than the ruby glass which owes its color properties to the presence of colloidal gold. These red glasses are of the greatest importance, for they are vital in railway and other signal lamps. Before their introduction various reds were on the market and some of these transmitted a part of the green, which was apparent to men whose eyes were not in normal condition. On one occasion an engineer, after a long period of service, was being tested as a routine matter for color blindness, when the officials were surprised to hear him calling lanterns first red and then

green at different distances from him. He thought the lanterns were being changed, whereas the change was due to the light transmitted by the lenses and the condition of his own eyes. These newer glasses are tested by the spectroscope and are known to transmit only red. They are called "spectroscopic red" glass. Safety is consequently greatly increased and under no circumstances can a normal eye see green rays transmitted through such glass.

More recently and entirely through research, new uses have been found for selenium compounds. Among others selenium oxychloride is found to be a remarkable solvent which is important from the standpoint of industry, as well as in methods of chemical control. Just now tellurium seems in a fair way to find a job, for automotive engineers have discovered that the use of small quantities of tellurium compounds, which have an offensive odor, make possible the elimination of the knock in internal combustion motors. The use of higher compression thus made possible means greater efficiency and the use of less fuel.

Some types of coal have been wasted because they are unsuited to present practice. There are coals in Illinois which are located favorably so far as industry is concerned but which do not lend themselves readily to coking by the common methods. Researches are in progress which show that other conditions of coking, such as low temperatures, may make it possible to use these coals in by-product coke ovens producing a metallurgical coke and permitting the recovery of the by-products.

In quite another direction research is at work to eliminate waste as represented by the annual losses in transportation due to improper packing and poorly designed

containers. It is estimated that losses due to these causes run considerably over $100,000,000 a year, so that research finds a profitable field in investigating the design of containers, the number, kinds and distribution of nails with reference to the load, and the kind of wood as well as the proper application of metal straps. Where pulp board boxes and various types of cardboard can be employed they lead to substantial savings.

Anyone who has had an automobile radiator freeze will probably agree that it is a waste which should be avoided. Research has not been idle with respect to methods designed to depress the freezing point of solutions. Some of the remedies suggested proved worse than the disease, for it is just about as satisfactory to have the radiator freeze as to have it fail from corrosion. A research worker has reported that one of these cheap chemical compounds, which is ideal in so far as depressing the freezing point is concerned, but which is corrosive, can be made noncorrosive by the addition of a small quantity of another cheap chemical. The resulting compound has now been on trial for much more than a year and, if its promise is fulfilled, the gain in the aggregate will be worth while and a business of fairly good proportions be established. Thus far, alcohol has been the only safe nonfreezing reagent and its ready volatility from the radiator solution has been its only fault.

Today when synthetic organic chemicals, which serve as perfume bases in many types of less expensive perfumes, are being made in America, it is amusing to think of the time when the foreign article of poorer quality could be sold here as high as $1200 per pound. Through research, the manufacture of these bases has been carried out successfully and the price is now about $200 per

pound. A similar story can be told in the case of many synthetic drugs and pharmaceuticals, flavoring extracts, and photographic chemicals, all of which are indirectly based upon scientific research. The ability of the organic chemist to construct a molecule almost to plans and specifications is one of the most promising signs in science today. It opens up tremendous possibilities, for it means designing a molecule to perform a certain mission and often in the presence of decidedly limiting factors. Devising a new compound for a particular use in medicine is an example.

Waterproofing processes are of industrial importance and of late fire-fighting fluids have been designed with greater attention to the scientific aspect of the problem. Fireproofing has called for the deposit in the fibers of materials which tend to retard burning but which at the same time resist both washing and wear and take nothing from the flexibility and general appearance of the fabric. Chemical salts have made this possible and have also added to the water-resisting properties of many fabrics. Industries are founded on the principles established by research in both instances. The waterproofing of cement and concrete is a difficult problem which has been fairly well solved by scientists, while cement itself, when applied with a "gun" or similar mechanical device is often used for both water- and fireproofing. An example of the first is the treatment of irrigation ditches where water is rapidly absorbed by the surrounding land, while an illustration of fireproofing is to be found in the coating of steel members in modern structures.

Two examples of savings may be drawn from dissimilar industries. A woolen mill in New England by installing the most recent methods for wool grease recovery was

able to pay the dividends on the preferred stock of the entire plant from the process. The grease was sold in a refined state as lanolin, suitable for use as a base in pharmaceutical operations. The corporation was a large one so that the net return on this piece of scientific work was very large indeed. In another part of the country an explosive factory was able, through the most painstaking application of scientific principles, to effect a saving of alcohol used as a solvent in the manufacture of smokeless powder, and during the war saved alcohol equivalent to 50,000,000 bushels of corn per year. Under the circumstances this saving was noteworthy not only from a monetary standpoint but from that of public welfare since it came at a time when conservation of food was essential.

In synthesizing an organic product, the usual procedure is for the research worker to isolate the active principle in the natural material. Having done this, he learns the chemical constitution of this active principle and then sets out to combine elements to give the same kind of a molecule. Obviously it is often a tedious matter. It is even more so than it would be carefully to take a building apart and then starting with the simplest materials like clay, lime, steel, iron, and the rest, make duplicate parts and erect a duplicate structure. It is more tedious, for the research man often needs to go way back to fundamentals and develop theories and principles to explain how the compounds are built up from the elements and then prove these principles by trial before he can succeed. All of this is made more difficult because he works with such infinitesimal units as molecules, atoms and electrons.

One of the marked successes has been the synthesis of

vanillin. Vanillin is the active principle in the vanilla bean which gives the extract its well-known flavor. Good vanilla beans contain 2 per cent of vanillin and these beans sell for around \$6 per pound, so that vanillin from beans is worth \$300 per pound. Chemists have found that by starting with oil of cloves they can cause a series of reactions to take place, which in the end gives them an organic body with the characteristics of vanillin. It brings about \$9.60 per pound and does the work of the \$300 article. It is perfectly satisfactory just as long as it is sold for what it is.

In one sense much of our gasoline is synthesized and all of it is due to scientific research. The proportion which might be called synthetic is that which is produced by the cracking process. It could only be considered synthetic in that it is not normally present, because cracking is the breaking down of more complex molecules, while synthesis is concerned with the building up of such molecules from less complex bodies. It is hard to realize that there was a time when gasoline was the least desirable of all the petroleum products. Research had not yet found a use for it. Then came the internal combustion motor and soon the problem was how to obtain more gasoline from crude oil. Many plans have been suggested but the commercial ones thus far involve the use of heat and pressure, so that the heavier hydrocarbons are split up into new bodies among which is gasoline. The larger the proportion of gasoline the more successful is the process.

It is difficult to realize the far-reaching effects of very small things which would easily escape the attention of an untrained observer. The scientist in a business organization does not merely confine his earning power to

work in his restricted field. He is a trained observer whose suggestions at any time may easily compensate for his annual remuneration. This is because he endeavors to be familiar with the ways of matter and appreciates the influence of time, temperature, pressure and concentration. There is recorded an instance where the continuation of certain stirring operations for an additional five minutes made the yield which had been below 80 per cent considerably above 90 per cent. One day when working with a new photographic emulsion which theoretically should have given good results, but practically had not, the research worker sneezed twice and to his surprise found that the desired result was obtained. It was just that slight additional time required at that stage of the development which had been previously overlooked. Recently a water heater has been perfected which heats sufficient water for the average domestic supply by utilizing heat which ordinarily is wasted at the edge of gas stove burners. A piece of aluminum the size of a walnut is sufficient to cleanse a ton of molten brass and give castings, which would otherwise be unsound and unsatisfactory. Traces of impurities have been found essential to more than one commercial product. When required, research determined what these impurities in the raw materials were and the optimum percentage. For example, tobacco in some areas became infected with a disease called "sand drown" soon after European potash was cut off. Investigation has shown American potash to be too pure, since the soil in question requires magnesium. This is an impurity in German potash and easily supplied from other sources for use with our potash.

No one appreciates the importance of small intervals

of time more than those who design the automobile engines, where the timing of the spark makes a tremendous difference in the efficiency. Physicists have worked on this problem, have considered all the factors, and have developed sensitive indicators with which as much as 30 per cent increase in efficiency has been obtained with multiple cylinder engines. Another interesting development in this field is the automatic carburetor, attempts to design which failed until a chemical engineer in co-operation with other scientists determined the variables and found the one, the control of which gave control of all the others. These men have found that, since the explosion of a gasoline and air mixture is in reality a complex chemical reaction, it must be susceptible to chemical control. The greatest efficiency is obtained with the most dilute mixture that can be burned under existing conditions. Results show that the greatest mileage can be obtained with dilute hot mixtures with a high degree of turbulence. As the temperature decreases the mixture must be made more concentrated to maintain the rate of reaction and since the turbulence decreases as the engine speed decreases, the reaction velocity must be maintained by increasing the concentration of the mixture as a greater load is put on the engine. This takes place in climbing grades, for example. It appears that proper chemical control can be obtained by arranging to increase the richness of the mixture with a decrease of the speed of the engine and to decrease the proportion of gasoline with increased speed. When the experiments are completed and engines provided with carburetors which automatically adjust for increase or decrease of load, millions will be benefited.

There are frequent instances of industrial failures due

to neglect of science. One group of men erected a plant and equipped it to manufacture metal parts for particular uses only to find that, by the time they were ready to manufacture, another group had obtained the business because of improvement in the alloys to be used; $600,000 was lost because of failure to use science to keep ahead of the procession. Another group lost an even larger amount because they failed to realize that they were about to engage in an essentially chemical business, and had never thought it worth while to consult a chemical engineer as to plans and processes. A city gas company was able to turn a loss of ten cents per thousand cubic feet into a profit through the service of science. Their practice was not only easily improved and made more efficient, but a large saving was made through attention to all meters. Many of these were found to be very inaccurate and, strange to say, were favoring the consumer. Replacements in plants, which always interfere with production, are annoying, are expensive, can be made less frequent, if indeed they cannot be entirely avoided by utilizing knowledge which is available and by developing new data. The output of a large paper mill has been greatly increased through improvements in the pulp-making process, giving a pulp of a strength to withstand the stresses in paper-making at top speed, and perfection in mechanical equipment decreasing the time of shutdowns for repairs.

WAYS TO PROCEED

Whatever the problem of the particular group may be, it is fairly certain that some other business man has been through something comparable and that science has

already achieved successes that should encourage him to employ it for his own benefit.

The manufacturer who realizes that without availing himself of the assistance which science is ready to offer he cannot hope to maintain his place in the commercial race, to say nothing of achieving advances, may find useful some suggestions as to how he may proceed safely upon a research program.

Some have been well satisfied to choose from among available candidates a likely fellow well grounded in science with a certain business turn and if possible experience in plant operations and research relative to production. Having found his man and tried him out in a preliminary way, such a manufacturer will turn him loose in the plant, for there is ample evidence to show that the trained scientist is a valuable observer who can soon pick up sufficient problems in nearly every plant to keep a considerable laboratory well occupied indefinitely. There is the example of a chemical engineer who, after some difficulty, managed to obtain employment in a pulp-making establishment. The superintendent of sulphite mill had no particular use for scientists, and so this engineer was given a position in the wood yard at very unremunerative wages which he accepted because he believed an opportunity existed for observation which would eventually earn him a chance for promotion. He soon noted unnecessary loss of pulp in the waste water and contrived simple devices for saving many tons of pulp per day. He also noted the uneven production of the mill and discovered both the cause and the remedy. Today he is in a commanding position with a large research staff assisting him and has developed so many new activities for the original corporation that its name is

seldom associated today in the minds of the people with the lumber business in which it had its beginning.

There is another instance of a young man who presented himself to the owner of a glass plant, stating that he had come to be employed as chemist. The owner had no intention of employing a chemist, but he knew something of the applicant and more or less in jest offered to take him on. It is stated that the young man in question had prepared himself particularly for that industry and it is not surprising, therefore, that within a short time he alone of all the employees not members of the family was entrusted with the valuable trade secrets, including the formulas for unique glass from which the greatest profits of the concern were derived.

Too often when men are chosen in this fashion and put to work they and the results they obtain are neglected by the management. In times past it has been customary to fit up some unused portion of the factory, provide inadequate facilities, no assistants, and no clerical help, and then forget the department very much as one forgets a New Year's resolution. It is surprising when real results are obtained under such conditions. If the man is qualified, however, he is pretty sure to work himself out of the dark corner, into adequate laboratory space, equipped to facilitate his work, and to be provided with assistants which prove an economy when properly directed. A good man in a poor laboratory of course promises better than a poor man in a complete laboratory. The former will justify early improvement in his facilities. The latter may prejudice a manufacturer against science in the future.

Often the problems which confront the manufacturer are so fundamental to his trade that they may be con-

sidered common factors and suitable for the attack of a group of manufacturers on some association plan. Many of these problems are so extensive as to require years for their solution and entail costs which a single concern may not feel to be justified, since the results will be of benefit to others in the same line of activity. On the other hand, such problems have been solved from time to time by large establishments which feel that even the temporary advantage which the new departures might give would well repay them for their investment. Certainly if a manufacturer is to derive the most from research, he will make the laboratory an intimate, internal and integral part of his organization and in times of industrial depression will scrap the plant itself rather than disband his scientific staff. Research properly and continuously supported under capable direction soon becomes just as vital to the business as the planning, the purchasing, or the sales departments. The president of one large company recently said that in the last twenty years he has had virtually to scrap his plant four times because of advances made in his research laboratory, and that every time the plant has been reconstructed it has proved of great benefit to him. He recognized that plants can be scrapped and machinery laid by with less danger to profits and even to the stability of his business than would be caused by the disbanding of the technical staff.

But as mentioned before, there are common factors in research for nearly every industry and the experience of many has proved that research on the association plan can be carried forward without detriment to competitive interests. The individual in the association who is best prepared through his own laboratory to

utilize the results of the research work continues to be in the same commanding position as he was before the association activity was undertaken. Fundamentals, therefore, can properly receive the attention of association research laboratories. The application of these fundamental principles to processes and products is best accomplished through the medium of a plant laboratory. Almost any research, therefore, can be undertaken either upon the individual plan or upon the association plan in which the association acts as the individual and controls the research. It directs the selection of problems and determines its continuance, depending upon results obtained, through an advisory committee or perhaps the secretary of the association or a technical director responsible to some appointed or elected group. The problem, therefore, becomes pretty nearly the same for either method of attack and some information will now be given relative to existing facilities for scientific and industrial research in the United States.

CONSULTANTS

A plan which appeals to many who hesitate to set up their own laboratory and assume the overhead before they have worked out a complete program of their own, involves the use of commercial laboratories and consulting chemists. Fortunately for American industry there are several laboratories of this type which specialize, which have a high standard of ethics, and which have to their credit many commercial achievements of considerable magnitude. Likewise certain specialists have become consultants and bear the same relationship to their clientele as does the attorney. Confidences are

respected, the clients' welfare and interests are safeguarded in every direction and through collaboration with other specialists these consultants bring to bear an unusual wealth of experience and information. There is one unique advantage in this line of attack, namely, that arrangements can be made so that the manufacturer is under no expense excepting when the consultant or commercial laboratory is actually engaged upon work in his interests. Nevertheless manufacturers find it advantageous to retain the consultant on a monthly or annual basis, to insure his continued interest and then arrange special methods of additional payment depending upon the program of work adopted. Even those manufacturers supporting their own research organizations find it advisable to retain independent consultants and specialists whose particular business it is to supply information on all current work that may be of interest. This includes patent searches, a study of laboratory work in progress, literature accounts of experiments, and even the scientific discussions before technical societies, from any one of which sources information of great value may be gained at any time. There might be recalled the experience of a chemist in Atlanta who in reading a technical article in "Industrial and Engineering Chemistry" thought of utilizing the hydrofluoric acid which is a by-product in the preparation of superphosphate from phosphate rock and sulphuric acid. From the acid which is ordinarily a great nuisance he prepared a fluoride much in demand for the preparation of enamels and in the last few years this business has totaled some two million dollars.

FELLOWSHIP

The fellowship plan in its various phases has always been appealing. Indeed some manufacturers support a number of fellowships without restriction as to the subject studied, firm in their belief that the development of men from whom they may choose to strengthen their own staffs will of itself pay for the investment. They realize also that many commercial achievements are directly traceable to principles discovered in so-called pure research and they are well satisfied if through their efforts something can be added to the truth which underlies all of our work with materials. More often fellowships are established in the educational institutions for work in some particular field of interest at the moment. Often arrangements are made whereby students refrain from publishing the results of their work until some stated period after they have been disclosed to the donor of the fellowship. That associations can profitably support fellowships is well proved at the Mellon Institute of Industrial Research of the University of Pittsburgh, where a specialty has been made of training scientists, who may afterward enter the industry, and at the same time carry on research upon industrial problems. Some of the associations supporting a fellowship there number as few as four members. Most of them are under fifty members but there is one that approaches two thousand members in the association organization. Work begun under these auspices has led to the development of still larger association activities, discussed in Chapter XIII.

The Massachusetts Institute of Technology has developed a plan which offers great promise, for it combines

an information service, with possibilities for specific research on production problems. It also involves the selection and placing of men who work in individual laboratories and goes a long way toward facilitating cooperation between the industries and the universities. The University of Michigan offers attractive cooperation to the manufacturers of that state.

The Government also offers its facilities to manufacturers, although naturally results cannot be retained as confidential. It is of great assistance to the manufacturer to be able to send to a government laboratory men of his own selection who can proceed with work under the direction of the trained personnel of the various bureaus and have available wonderful library and laboratory facilities. The Bureau of Standards, the Bureau of Chemistry, the Bureau of Mines, and other scientific departments have been quite successful in this field and through their efforts some associations have undertaken work in which they might not otherwise have become interested. Within the last few months the manufacturers of heavy clay products have entered upon a program of this sort and since so much of the work in ceramics is based upon empirical methods and personal experience, there is reason to believe that substantial strides can be made in the very near future.

With the existence of facilities for the pursuit of the plans thus briefly discussed, the manufacturer may properly ask how he is to get in touch with the specialist or with the organization who can be most helpful to him. It is not difficult to investigate not only the plan as applied to a particular group of problems but the personnel that might be engaged as well. The National Research Council at Washington endeavors to maintain an

adequate file of research men and women who are competent in the various fields of science. Upon request the Council furnishes lists of names which the manufacturer can investigate. Some of these lists are based upon data accumulated for the use of the Government during the war and the research record of more than 25,000 people is already at hand.

The officers of the Federated American Engineering Societies, American Chemical Society, American Physical Society, American Association of Economic Entomologists, American Association of Pathologists and Bacteriologists, American Ceramic Society, American Electrochemical Society, American Geographical Society, American Medical Association, American Mineralogical Society, American Phytopathological Society, American Psychological Association, American Society of Biological Chemists, American Society of Refrigerating Engineers, American Society of Zoologists, Association of American State Geologists, Geological Society of America, American Society for Testing Materials, American Society of Mechanical Engineers, Society of Automotive Engineers, American Institute of Electrical Engineers, American Institute of Mining and Metallurgical Engineers' American Institute of Chemical Engineers, and Society of Economic Geologists are in position to recommend specialists. In most industrial centers there are now to be found local sections of the great national technical and scientific societies who are in touch with large numbers of their fellows and in position to make recommendations. The government bureaus are likewise in position to render such assistance so that there seems no reason why an interested manufacturer should hesitate to engage upon research for fear that a suitable staff can-

not be assembled. The men are available, competent and ready, facilities exist in many places, and a satisfactory plan can certainly be evolved for work upon any special group of problems.

Grand Central Terminal, New York City, looking south from 50th Street, before and after electrification.

CHAPTER VIII

CONTRIBUTIONS OF SCIENTIFIC RESEARCH TO THE DEVELOPMENT OF MECHANICAL ENGINEERING

J. A. Hall

HIGHER STANDARDS OF LIVING MADE POSSIBLE BY THE ENGINEER

While engineering has been defined as the science of utilizing the forces and materials of nature for the benefit of mankind, one of the chief contributions of mechanical engineering to this end in this country has been to enlarge the production per worker, and thereby to increase the average wealth and physical well-being of the people. This productive capacity has been growing at such an accelerated rate during the past few years that the dream of the ages, universal well-being, seems to be nearly within our grasp. Dexter S. Kimball, past president of the American Society of Mechanical Engineers, has frequently emphasized this social service of engineering as shown in the following extract from his presidential address: "Our civilization differs from those that have gone before, and from some that exist even today, only in one important particular. Our philosophy and our religions are built up for the most part of beliefs inherited from our forefathers, but our power to pro-

duce the necessities of life, to feed, clothe, and house the multitude, stands out as a thing apart and unlike anything that has yet appeared on this earth so far as we have record. This power has come to us through the use of what we are pleased to call the 'scientific method,' by which we aim finally to replace the words 'I think' with the words 'I know' in all our mundane activities."

Under the old handicraft methods of manufacture, the production per individual was so low that the attainment of a high degree of civilization by even a small part of the population could be secured only by the degradation of the many. Thus, the wonderful civilization of the Greeks and Romans in reality belonged to about five per cent of their people, while the remaining ninety-five per cent, who did practically all the manual work, lived as slaves or eked out a bare existence in miserable hovels. The level of comfort of the mass of the people in any thickly populated country remained indescribably low until handicraft methods of production were superseded by machine methods, and now the much greater production due to the scientific attack on the problem bids fair to realize the dream of universal well-being.

In a recent article Mr. E. M. Herr, president of the Westinghouse Electric and Manufacturing Company, pointed out that the value of manufactured goods annually produced in the United States increased three hundred and sixtyfold between 1812 and 1919, while the population increased sixteenfold. Decreasing this ratio by a third, due to the difference in commodity prices, makes the figures hardly less impressive. In the earlier period mentioned, carpenters and blacksmiths received about a dollar a day, while the pay of textile mill oper-

atives in New England as late as the middle of the last century was only three to four dollars a week.

In this country there is today an automobile for every eight people, and a telephone for every three people, making the average better than one to a family in the latter and one to two families in the former case. If the figures for pianos, talking machines, and wireless outfits were collected, they would undoubtedly be similarly high. This increase in the distribution of luxuries has been accompanied by a decrease in working hours and a decrease in the proportion of the population at work, as well as by a large increase in wage rates.

While many labor leaders claim that this improved condition of the workers is due largely to the efforts of the labor unions, it is well to remember that without the work of the engineer, scientist, and inventor in devising means of increasing output, no advance in real wages would have been possible. Furthermore, when it is realized that in most of our manufacturing establishments an increase in wage rates of 15 to 20 per cent for all persons on the payroll without raising the production per individual or the selling prices, would more than wipe out all returns on the capital invested, it becomes apparent that wage increases secured without increase in output only affect the relative position of different classes of workers. Improvement in the average condition can only come from the application of the principle "higher wages and lower costs"; therefore manufacturer, labor leader, and social worker should all be interested in the contribution of the engineer toward the realization of this ideal.

The continual development of labor-saving machinery is one of the main reasons for the changed conditions.

The progress made in the methods of generating and distributing power plus an enormous increase in the amount of power generated is equally important in furnishing the energy required to operate this machinery. The improvement in and the better control of the processes of production so as to eliminate waste of materials and of human effort is also playing an important part. All three of these owe a great deal to the research work of the mechanical engineer, and this is playing a still more important part in the greater advances which are going on at present or will come about in the near future.

While making all these claims for the engineer it is well to note that this progress would be impossible unless our social system provided freedom of individual initiative for the development of ideas and also an abundance of capital for meeting the expense, as a large surplus of production over requirements for consumption is necessary to provide capital for the building of machinery, construction of the power plants, and carrying on of the research work.

NECESSITY OF PROPER TRAINING FOR RESEARCH WORK

The industries having their scientific background in mechanical engineering owe the greater part of their early technical development to mechanical ingenuity. Because of this fact the inventor, having perhaps only a smattering of knowledge of the scientific principles involved in his work, has always occupied a position of importance, and even today many men in these industries feel that fundamental science has little to contribute to their progress. This mistaken attitude has resulted frequently in the loss of a great deal of money and effort

in making useless experiments or in trying to develop ideas which violate the laws of science. According to the stories of some of his early assistants, even the great George Westinghouse, inventor of the air brake and founder of the Westinghouse Electric and Manufacturing Company, personally spent a large amount of time and money on a rotary steam engine which he would never have considered if his knowledge of thermodynamics had been a little greater at that stage of his career. So much money is being wasted along such lines that a few illustrations are given in the following paragraphs:

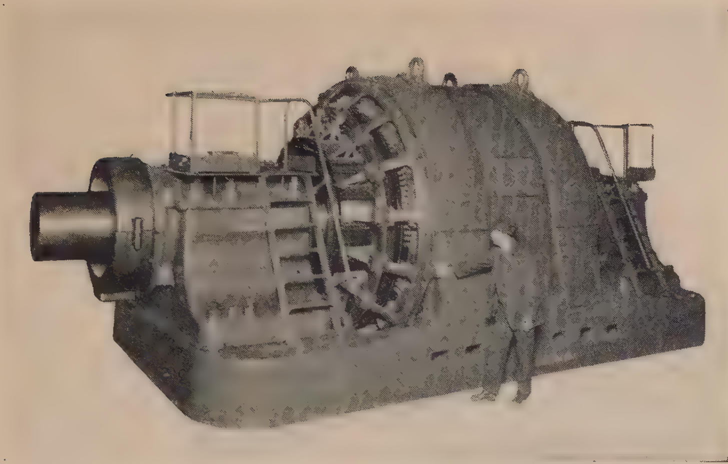
The impossibility of securing power from some mechanical device, generally called perpetual motion, is generally recognized today even among nonscientific men. However, only recently a man who had done outstanding work as a designer and builder of machinery conceived the idea of a machine which would isolate centrifugal force so as to make it do useful work. He believed that this machine placed in a car and driven by a small motor to keep it in motion would give sufficient force to pull the car. Both the mechanism devised and his analysis of the forces in it were so ingenious that it was only with difficulty that the flaw in the reasoning was located. However, the first law of nature, "One cannot get something for nothing," should have been sufficient to save the money spent in trying to develop this idea.

The belief that some change in the mechanism can produce a large increase in the power given by our present engines is little better than the perpetual motion scheme discussed. Yet a large amount of money is spent each year by business men in helping inventors develop such ideas, and every little while we see announcements that a new engine has been built which will give several

times as much power as present engines of the same size, and do it on a fraction of the gasoline consumption.

Now the energy of the engine comes from heat, and each gallon of gasoline contains a quantity of heat which can easily be determined. The heat comes from the burning of this fuel, and oxygen is required to complete the combustion. Again, the amount of oxygen required to burn this fuel is known, and the exact amount of air or other supporter of combustion required to furnish this oxygen can be equally well determined. The above facts enable one to determine almost exactly the maximum amount of work that can be done by a given size of engine with a given amount of fuel. Finally, the knowledge of thermodynamics enables one to determine the per cent of this heat which can be transformed into useful work, and what proportion must be lost in the exhaust under different conditions of operation. If the proposal of each inventor of a new type of internal combustion engine were analyzed on this basis before building one for experimental investigation, a great deal of time, money, and effort would be saved every year.

A few years ago announcements in the press stated that a prominent inventor had produced a device which among other uses made possible very long range firing from guns which would require no recoil mechanisms. Combustion of the powder rather than explosion was given as one of the underlying reasons. Now the laws of Newtonian mechanics show that long range for any projectile not propelling itself requires high muzzle velocity, that high velocity can be secured only by a force acting on the projectile for an appreciable time, and that this force acts backward on the barrel of the gun through the same time, and therefore imparts the same mo-



A 4000 horsepower 600 volt motor. Two such motors together form an 8000 horsepower unit for a reversing steel rail mill.

"The Fingers of Man." A McMyler 350 ton hammer head crane installed at the League Island Navy Yard. Electrically operated. Total lifting capacity in excess of 500 tons.

mentum to the barrel as to the projectile. The barrel of the gun is generally so heavy that this momentum causes a comparatively small velocity, and the energy of recoil is absorbed by the recoil mechanism in a few inches or feet of movement. However, a high velocity of the projectile means a high momentum, and this high momentum transmitted to the gun barrel must be overcome either by a recoil mechanism or by deformation in the metal of a very heavy gun barrel attached to a rigid foundation. Einstein may have modified the Newtonian mechanics by a millionth of one per cent, but even knowledge of this refinement does not change the absurdity of trying to develop the above idea when the fundamental theories are understood.

Lack of appreciation of the laws of elasticity has been the cause of many useless experiments in our metal working establishments. Only recently one machinery manufacturer claimed that he was furnishing much stiffer spindles than his competitors because of the particular type of steel or heat treatment used, and a carelessly made test in the laboratory of a customer seemed to substantiate his claim. A competing concern then spent a considerable sum on experimental work to prove both to its own force and to the customer, that within their elastic limit all steels have very nearly the same stiffness. This fact is well known to all men who understand the theoretical background of the subject, and has been proved by so many experiments that these tests seemed much like trying to prove a law of nature. However, many experiments are being made in industrial plants today which would be equally unnecessary if the men in charge of them understood the fundamentals of mechanics, thermodynamics, and other branches of engi-

neering science, and had the mathematical ability to apply them.

Another group of losses in some of our present work comes from the lack of knowledge of experimental methods on the part of the men doing the work. An examination of the data, as well as the results of the investigations carried on by such men, often shows the work to be nearly worthless. Absolute faith may have been placed in figures given by measuring apparatus which had not been calibrated, and obviously incorrect results therefore accepted as true. Pyrometers may have been installed where their readings of temperature were affected by radiation losses. Rates may have been determined by use of a stop watch measuring such short time intervals that errors of one or two fifths of a second, easily made by the observer, might cause a large percentage of error in the result. Supposedly accurate measurements may have been made from points of reference subject to distortion, as was the case in the experiments on stiffness noted in the preceding paragraph. Important observations may have been omitted, making it impossible to check the figures or limiting the usefulness of the investigation to the particular result wanted at that time. Because of the frequency of errors of this sort, it is necessary to examine carefully the results of tests made in many of our manufacturing plants to see if confidence can be placed in them.

Frequently money is spent on research work without first getting the benefit of the successes or failures of others in the field. Most progressive manufacturers have come to realize that more is gained by exchange of ideas in scientific research than by secrecy. Many articles giving the results of work carried on by other concerns

can be found in the journals of the engineering societies. Possibly some of the information desired may have been secured by research work at the United States Bureau of Standards or at some research institution such as the Mellon Institute at Pittsburgh, the Lewis Institute in Chicago, or at the laboratory of some engineering school, and this information may be available in the publications of these organizations. Duplication of work due to the failure to search the literature of the subject is, therefore, another source of loss.

There is a mistaken idea among many executives that the research man spends most of his time in the testing laboratory, and that when given a problem, he immediately sets to work making laboratory experiments until he gets the answer. The real investigator spends considerable time analyzing the problem, studying the underlying theories and laws of science involved, and searching the literature of the subject to find what others have done. After this is completed, a comparatively short time in experimental work may be all that is necessary to determine the value of the mathematical or theoretical analysis he has made and to secure the additional information required.

The choice of the right man to carry on industrial research work becomes the most important consideration, and the laboratory equipment becomes purely secondary. In fact, the expense for laboratory equipment to get very valuable results may be practically negligible. Ingenuity and a vision of the possibilities of new proposals are essential qualities for such a man. However, if the work is to be done most effectively, these must be accompanied by a thorough understanding of the facts and theories of science underlying the subject, experience in experi-

mental methods, knowledge of the sources of information, and a large measure of common sense.

POWER DEVELOPMENT

A. Steam Power Plants

At the conclusion of a trip through a cotton mill recently the owner remarked to the writer that the processes were practically the same as when he entered the business nearly fifty years before. "The spindles may run a little faster," he said, "and better control devices may permit one operative to tend more spindles, but aside from these few improvements there has been no change." The surprising part of it was that this remark was made without any suggestion of apology or regret. In direct contrast to this is the attitude shown in a paper on Power Plant Evolution, written about two years ago, by Mr. C. F. Hirshfield, chief of the research department of the Detroit Edison Company. After noting the enormous progress of the past twenty years, he pointed out that the limit of development of our present stoker-boiler-turbine type of power plant was very nearly reached, and no improvements which might call for radical changes in equipment were in sight. Then, instead of saying that charges on account of possible obsolescence might be reduced, he continued with the statement that some revolutionary development was sure to come in the near future, and that allowance for depreciation should be made higher rather than lower. This spirit is found in most industries where scientific research is appreciated, and as it is particularly prevalent in power plant development, this is chosen for the first discussion.

1. Sleet is the great enemy of aerial lines. A modern alternative is to place the wires in lead covered cables. 2. Manhole under Broadway and 34th Street, New York City. About 10,000 telephone lines are contained in the cables shown. 3. Typical section of the New York-Chicago cable crossing mountains in Pennsylvania. This cable contains about 150 circuits. The open wire lines originally carried about 30 circuits. 4. Section of a modern lead covered telephone cable showing the 2400 wires fanned out. These wires are insulated from one another by a special tissue and very tough paper. The outside diameter of the lead sheath is 2⅝". 5. The first telephone central office in the city of Boston. Note the roof structure used in bringing the wires, all of which were aerial, into the office.

Only a little over one hundred years have elapsed since James Watt, by improving the crude engines used at that time only for pumping water out of mines, created a steam engine capable of driving machines, and thereby became the father of the industrial revolution. While improvements in equipment for converting steam to mechanical energy came steadily during the nineteenth century, they seem slight compared with the revolutionary progress of the last two decades mentioned above. In 1900 the Interborough Rapid Transit Company installed in its Fifty-ninth Street Station 7500 kilowatt twin compound steam engines as the last word in power development. These units cost forty dollars per kilowatt, and required about seventeen and a half pounds of steam per kilowatt hour. Only nine years later, due to increased demand for power and the possibility of lower power costs, low pressure turbines were combined with the engines, doubling the capacity and reducing the steam required per kilowatt hour to fourteen and a half pounds. In 1915 one of the original units was replaced by a 30,000 kilowatt turbine costing about nine dollars per kilowatt and having a steam consumption of eleven and a half pounds per kilowatt hour. A year or two later the combined engine turbine sets installed in 1909 were replaced by 60,000 kilowatt turbines having a still lower steam consumption. In every case the increased economics of the new equipment were so great that the company could not afford to continue using the older types, even though they had not begun to wear out.

This great decrease both in steam requirements and investment costs, combined with the large increase in size and its consequent reduction in attendance charges per unit of output, must have some cause back of it,

especially when it has occurred in such a short space of time. For the increase in steam economy, credit must first be given to the knowledge of the properties of steam and the laws governing its action which the research work of the physicist and engineer has furnished. The particular value of this is that experimental work does not have to be done blindly, but that possible savings can be calculated before the investigation is started, and definite standards can be obtained against which performance can be checked and correction factors determined where this is necessary.

For instance, anyone familiar with the properties of steam can calculate the exact amount of power available in each pound of steam when delivered to a steam engine or turbine at a given pressure and temperature and exhausted from that unit at some lower pressure or drawn into a condenser at a given vacuum. This information provides a yardstick against which the actual performance of different units can be measured, and the effect of changes in design determined. Furthermore, the knowledge of the properties of steam makes possible the immediate design of nozzles, vanes, and steam passages in the turbine of nearly the proper size, although a great deal of experimental research is required to determine the slight changes required to allow for the effect of friction, eddies in the flow, and other disturbing influences not fully included in the theory. A large number of such relatively small studies, rather than a few spectacular inventions, are responsible for the attainment of the high efficiency of the large modern turbine in which nearly 80 per cent of the available heat of the steam is converted into mechanical energy.

Just as the energy available in each pound of steam

under certain conditions of operation can be determined, so the additional amount of energy made available by changes in the operation, such as increasing the pressure, raising the temperature of superheat, or lowering the vacuum, can also be calculated. If the advantages to be gained seem to warrant the expense, further mathematical and experimental research may be carried on to determine the best method of applying the change.

The laws of thermodynamics show that more power can be derived from steam if the range of temperature through which it is used is increased. The exhaust level is reduced by lowering the vacuum in the condenser, and this has been carried so far in modern central station practice that the steam leaves the turbine at a temperature of 80° F., or cooler than the air on an average summer day. Before this level was reached, many investigations had to be made, varying from problems of heat transfer in condensers to centrifugal stresses in the large turbine rotors necessary because of the great amount of space required by a comparatively small weight of steam at such low pressures.

As the expense of further reducing this temperature seems prohibitive compared with the additional advantage to be gained, attention at present is being directed to the upper limit. Detail investigation into the properties of materials at high temperatures have made possible safe operation at 700° to 750° F. under high pressures. At these temperatures cast iron "grows" slightly and loses its shape, while some kinds of steel become weaker or much more brittle, so these are eliminated in the dangerous sections. Undoubtedly, materials which can be used commercially under higher temperatures will be developed, but as steel begins to get red at 750°, work-

ing in a room containing boilers and pipes which are under steam pressures of 350 pounds per square inch and which are heated above this level, hardly seems attractive.

Increasing the steam pressure without changing the maximum temperature to which the steam is superheated, also makes a higher percentage of heat in the steam available for power, so this possibility has attracted a great deal of attention during the past two years. Unfortunately, the knowledge of the properties of steam above 500 pounds per square inch pressure is incomplete, so the exact calculations of expected savings and of detail design are impossible. However, a considerable amount of research is now being carried on under the direction of a committee of the American Society of Mechanical Engineers to fill in the gaps. In the meantime, an experimental installation to operate under a pressure of 1200 pounds is being made by the Boston Edison Company in its new Weymouth plant, and since that has been started several others have been announced, including one in England to operate at 3200 pounds pressure. The reason for the latter choice is that at this pressure and at a temperature of about 700° F. water reaches a critical point where it passes into steam without the violent boiling of lower pressures. The knowledge gained from these experimental installations will point the way to future development.

Another effort to utilize the higher temperature range without requiring such great pressures is by having a mercury vapor turbine combined with a steam turbine. The boiling point of mercury at a comparatively low pressure is near the maximum temperature which can be used with our present structural materials, and its

temperature when condensed at a low vacuum is still above that of high pressure steam. The mercury turbine, therefore, takes out the energy at the higher temperature levels, while its condenser acts as a boiler to furnish steam for the steam turbine. A great deal of research work was carried on by Mr. W. L. R. Emmett, at the Schenectady plant of the General Electric Company before this development was at all possible, and the first trial equipment is being installed in Hartford at the central station of the local power company.

With all these radical developments being tried out, it is difficult to predict what type of turbine will be found in the power plants of twenty years hence, or whether the turbine will be there at all. In fact, since the researches of the physicist have shown the enormous internal energy of the atom, the possibility of utilizing this as a source of power is one of the dreams of the present which may be converted into a reality of the future.

While all these improvements have been under way in turbines, changes in boilers and furnaces have kept pace. Here again, the possession of exact standards with which to compare the attainments of different designs has been a great factor in the rapid growth. Measurements of the amount of water fed to the boiler and the coal burned give a rough check on the performance, but if analyses of the coal, ash, and flue gas are made, and records kept of a number of pressures and temperatures, the source and amount of practically all losses are determined. Moreover, the proportion of these losses, which is theoretically, as well as practically, unavailable for transfer to the boiler, can be calculated from the data of the tests. As a result, here also, projected improve-

ments do not have to be experimented with blindly, but their possible value can first be determined, and then the improvements obtained checked against these figures.

The study of the laws of heat transfer in boilers constituted one of the research investigations of particular value, much of this work being done at the United States Bureau of Mines laboratory. The general knowledge of the subject included the fact that while the plates and tubes of the boiler exposed to the fire received a part of their heat by radiation, all other surfaces absorbed heat only by the passage of the hot gases over them. The old idea of the latter was that the rate of heat transfer was governed by the area of the exposed surfaces and by the difference in the temperature of the hot gases and of the water. While boilers designed in accordance with this idea were highly efficient when operated at their rated load, the heat losses increased rapidly above this point. The investigations mentioned above brought out the new fact that the velocity of the hot gas over the surfaces of the boiler was one of the most important factors governing the rate of heat transfer. The explanation often given now is that a colder film of gas tends to form next the metal, but if the velocity is sufficiently high to cause turbulence, this film is continually torn away and fresh, hot gas keeps coming in contact with the heating surfaces.

As a result of this development, boilers were designed with smaller gas passages to increase the velocity and with larger furnaces to burn more fuel, and it was found that two to three times the former output could be obtained with little drop in efficiency. Of course, the new arrangement made a greater intensity of draft necessary, and this had to be supplied by blowers; but the greatly

reduced cost of investment for a given capacity made this improvement so profitable that it has become the standard for all large power plants.

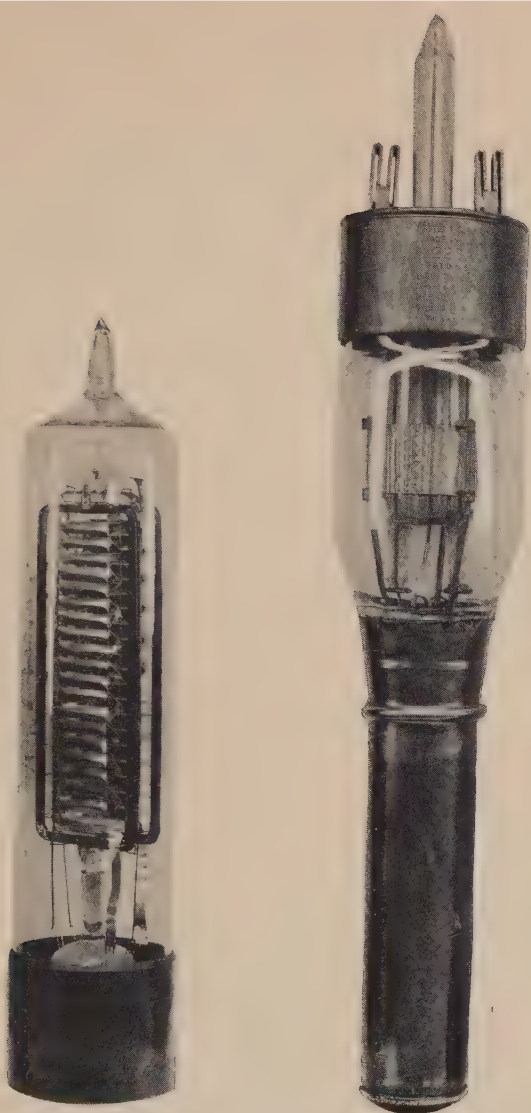
Another saving from this greater knowledge of the laws of heat transfer has come in the development of waste heat boilers. Formerly, it was considered impracticable to use any of the waste heat from cement kilns, smelting furnaces, and similar units, because the temperature of the flue gases was so low that it was necessary to use very large boilers compared with the amount of heat saved. Now, a large amount of this heat is used in making steam in smaller, high-gas-velocity boilers with blowers or fans to furnish the extra draft required, and the savings are sufficient to pay a large return on the capital required to accomplish it.

The elimination of the fireman of the picture books shoveling coal before the open furnace door was one of the achievements of the automatic stoker in large power plant practice, and now the pulverized coal burner is bidding for the leading position. The development of this method of combustion has been full of research problems. As the coal travels with high velocity, the determination of the size of the furnace and method of admission of air to insure proper mixing with the fuel and complete combustion of the latter, involved a great deal of study. The problem of furnace linings also required considerable investigation, as the temperature of the flame is extremely high, and heat is radiated in all directions. It was found that the best fire brick as ordinarily used could not stand up for any considerable time under these temperatures, so studies in the heat conductivity of different kinds of brick were made, and a new type of furnace designed where the backs of the

fire brick were cooled by the incoming air. The withdrawal of the ash when its fusing point is below the temperature of any part of the furnace, the maximum coarseness of pulverization of the coal consistent with complete combustion, and many similar problems, had to be investigated before pulverized coal furnaces for power plant boilers were considered anything more than experiments. Within the last two years, however, they have been installed in several large central stations, and the results show that a larger percentage of the heat of the coal is transferred into the water of the boiler than by any other method. An added advantage of this method of combustion is that low grade coals, formerly of little value, can be used to generate steam nearly as efficiently as the better fuels.

Another direction in which the cost of heat and power has been reduced is in the development of steam pipe coverings. The fact that the heat lost through 1000 square feet of bare steel pipe containing steam at 100 pounds per square inch pressure, requires 300 tons of coal annually to replace, shows the importance of this subject. A great deal of work has gone into the investigation of the heat insulating qualities of different materials, so that the best available combinations are now known. Another type of research is illustrated by the studies made at the Mellon Institute of Industrial Research for the Magnesia Association of America on the effect of different thicknesses of one kind of insulation. From such studies it is possible to calculate the proper thickness of insulation to use for a given cost of steam, and a given return on the investment involved.

The illustrations given above show but a few of the ways in which the spirit of investigation and research is



Two record makers. The vacuum tube shown on the left was used in 1915 in the first transmission of the voice across the Atlantic Ocean. The tube on the right was used in 1923 to accomplish the same end in a manner which approached much more closely the conditions required by commercial service. The new tube is about 400 times as powerful as the old. Both are the product of the Bell System Research Laboratories.

increasing the efficiency and reducing the cost of steam power generation. As an increasing supply of cheap power is absolutely essential if the production per individual is to continue growing larger, it is interesting to note that in spite of greatly increased costs of labor and materials, the cost of central station power has decreased greatly during the past twenty years. The growth of these plants has been enormous, the per capita consumption of current purchased from such plants going from 23 kilowatt hours in 1900 to 435 in 1920. The greater part of this increase is due to the larger requirements of manufacturing establishments, which are using much more power than they did twenty years ago, and, in a majority of cases, find it cheaper to purchase this energy from the nearest central station than to manufacture it themselves.

B. Hydraulic Turbines

The hydroelectric power plant holds a place second only to the steam central station in furnishing the energy required by the industries of this country, and, due to the progress in economical transmission of electric current over considerable distances, the value, particularly of the larger water powers, has increased enormously in the last twenty-five years. It is, therefore, interesting to read in a book on this subject published less than twenty years ago that "Like all other matters pertaining to hydraulics, the turbine has made little progress in the last fifty years." At that time the best units at Niagara were operating at 76 per cent efficiency, and a guarantee of 78 per cent had been specified in 1904 on a 10,500 horsepower turbine, the largest ever built up to

that time, to be installed at Shawinigan Falls. In direct contrast to the above, both as regards size and efficiency, the first of a series of 55,000 horsepower turbines was put into operation at the Queenstown plant of the Hydro-electric Commission of Ontario in 1922, and attained an efficiency of 93 per cent. Units of 70,000 horsepower are now under construction for the Niagara Falls Power Company, and equally high efficiencies are expected.

The efficiency of these plants becomes of great importance, as the demand for power increases up to the limit of supply. The total energy available in any water power is a product of the amount of water flowing down the stream in a given time and the difference in level of this water above and below the dam, and when all of this water is run through the turbine, as is the case in many installations for a large part of the year, the limit of return on the investment is reached. As the first cost of the dam, storage reservoir, and power plant, and also the operating charges, are nearly the same for an installation of high as for one of low efficiency, an increase of from 78 per cent to 93 per cent represents a very great additional return. In fact, for a water power where 100,000 horsepower is available, the saving alone would be sufficient to supply all the industrial and domestic requirements of the average city of 50,000 people.

The rapid improvement of the past twenty years, after the nearly static condition of the previous fifty, is due to the scientific analysis of the whole problem in terms of the fundamental theories of hydraulics, and to extensive experiment in order to eliminate all possible losses. A good illustration of the sort of work done is found in the improvements in design of what is known as the draft tube. This tube is the pipe which receives the water

leaving the turbine, and discharges it into the tail race. As the turbine must be placed some distance above the level of the water below the dam so as to make it accessible for inspection and repairs, the energy remaining in the water, due to this elevation, can be utilized by the wheel only by taking advantage of the suction of the solid body of water flowing downward through this air-tight tube.

A study of this problem showed that the water left the turbine with considerable downward velocity, and if this was reduced to the lowest practical point before discharging the water into the tail race, the kinetic energy due to the velocity could be utilized to increase the suction on the turbine wheel. A further study of the problem by use of tubes inserted inside the tail race showed that under many conditions of operation the water had a considerable spiral or whirl velocity, and as a result of the centrifugal force thus generated, most of the discharge moved along the surface of the tube while the velocity at the center might be actually upward. This led to a study of the vortex, the most common form of which is found when water is running out of a round wash basin through a hole in the center. Here the water starts from a nearly quiet condition on the outer edge of the basin and ends in a whirling and downward motion in the center. So by working out an arrangement to invert this process the spreading draft tube was finally evolved. In this design not only the suction due to the height of the turbine above the tail race is utilized, but a maximum amount of the energy due to both the downward velocity and the whirl velocity of the water is conserved, and made to increase this suction.

This illustrates but one of many important studies

which have been made to eliminate the losses in hydraulic turbines, and to put the industry on a scientific rather than a rule of thumb basis. How well this work has been done is shown by the fact that in the largest installation to date, the total losses in friction and eddies amount to but seven per cent of the total energy available. Moreover, when the enormous energy stored up in the over six hundred thousand pounds of rotating parts or in the millions of pounds of water flowing through the flume in this installation is fully realized, no one would be so foolhardy as to risk building such a plant unless the "I think" of the rule-of-thumb designer had been replaced by the "I know" of the engineer who is working from the results of scientific research based on the fundamental laws of hydraulics.

With the rapid development of hydraulic turbines, it is little wonder that the growth of the new industrial South is going hand in hand with the development of the southern water powers. The construction of the St. Lawrence waterway to permit ocean-going ships to travel to the Great Lakes will also make possible the development of 4,000,000 horsepower which will vitally affect the industrial development of Quebec, Northern New York, and New England. The proposed exploitation of the Colorado River will be of equal importance to the Southwest. Some day, perhaps, the fifteen million tons of coal required each year to furnish the power which might be developed at Niagara Falls will be considered too high a price to pay to save that scenic wonder for the tourist, and then another four to six million horsepower may be available to increase the wealth and industrial growth of New York State and the adjacent parts of Canada. Throughout all this development the work

The same shop under poor and good illumination.

of the engineer in increasing the size and efficiency and in reducing the cost of the turbines to be used in these plants, is of prime importance.

C. Internal Combustion Engines

The source of power of greatest convenience in small units and the one most familiar to the average individual is the gasoline motor. It is, therefore, interesting to note that less than fifty years ago George B. Brayton was experimenting in Providence, Rhode Island, with the first internal combustion engines ever built in this country. He called them "Ready Motors," probably hoping that they could be started more rapidly than a steam engine with a cold boiler, which was the only successful type of heat-power apparatus in his day. One of these motors, which was bought by Brown University to drive the first arc-lighting generator in Rhode Island, can still be found in the Engineering Laboratory of that institution, and alongside of it is a Liberty airplane engine. The former weighs fifteen hundred pounds and develops two horsepower, while the latter is about half as heavy and has an output of four hundred horsepower. Brayton died before completing his experiments, and left no one to carry on his work. However, about two years later a successful engine was built in Germany working on what is called the Otto cycle in honor of its inventor, and this became the first step in a continuous development.

It is a tribute to scientific research which furnished the fundamental knowledge of thermodynamics, that before this first successful engine was built, the ideal sequence of operations, or heat cycle as it is called, on which such a machine could best operate was laid out not

only by its inventor, but entirely independently and several years earlier by a French engineer, who, however, did not build an engine. Still, later, when Dr. Rudolph Diesel started to design an internal combustion engine to use heavy oils as fuel, he also laid out the theoretical heat cycle to be used before experimenting with the first engine. Other cycles have been proposed, but analysis in terms of the fundamentals of thermodynamics has shown them deficient either due to low efficiency or to the size and weight of the engine required for a given power output. This background of fundamental theory undoubtedly accounts to a large extent for the rapid development of engines built on these two cycles.

There are probably few lines of development in the past twenty-five years where so much money has been wasted on the wild-goose-chase type of development as in the automobile and airplane engine field. This waste of time and money seems a pity in view of the fact that if certain data on any present or proposed engine are known, such as the bore, stroke, speed, compression pressure, and fuel to be used, it is a simple matter to calculate the total possible power output if operated at 100 per cent efficiency under the best possible conditions. With this information in hand and a proper knowledge of fundamentals, research studies can be kept within the limits where improvements are possible.

An intensive study of airplane engines was made along these lines during the war, and, as a result, a number of types came surprisingly near the theoretical efficiency of a perfect engine of the same size and compression pressure. Every detail in which it was felt that the actual engine fell short of the theoretical cycle was investigated, and new designs were tried out to eliminate

losses as far as possible. The engines were tested, using some form of dynamometer in which the horsepower developed was measured, and comparing this with the amount of gasoline used in a given time. In this way the changes in detail design which were required to give the greatest power and efficiency were worked out in a surprisingly short time.

The development of exhaust manifolds makes an interesting illustration. Many racing car drivers feel that they get more power from their engines if the exhaust from each cylinder comes out in a separate pipe in the side of the hood. The deafening noise undoubtedly has a great deal to do with this belief, for comparative tests of this practice and of the use of a single, well-designed pipe, or exhaust manifold as it is called, connected with all the exhaust ports of the engine, showed a small increase in power, using the latter. The explanation of this result is that a certain amount of energy remains in the exhaust gas as it rushes out at high speed, and if the exhaust from one cylinder is slowed up gradually in a manifold which is designed with long curves so as to avoid losses in friction, it creates a suction which draws the exhaust more rapidly from the next cylinder to open. Of course, the best design of this exhaust manifold involved a great deal of study and experiment. Studies similar to this one are now doing a great deal to improve the design of the automobile engine in other respects.

Another type of research deals with the study of changes in the fundamental conditions of operation rather than in detail design. For instance, a survey of the theory underlying the Otto cycle shows that both the power and efficiency of an engine of a given size are

increased by using higher compressions. The disadvantage of this change lies in trouble from "knocking," which is the term applied to the hammer-like blows so familiar to most motorists when traveling at low speeds with the throttle wide open and the spark advanced, and particularly prevalent when there is much carbon deposit in the cylinders. For a long time it was felt that this was due to the hot carbon causing premature ignition of the mixture in the cylinder, but investigations of the subject have shown that it is really due to a different and much more rapid kind of explosion commonly called detonation. The distinction is somewhat the same as that which exists between an ordinary black powder and a dynamite explosion.

While the reason for this difference is not fully understood, studies of different fuels have shown that they are not all equally liable to this kind of explosion. For instance, experiments made with a mixture of gasoline and benzol for fuel have shown that the danger of knocking with moderate increase in compression is practically eliminated if ten per cent of the latter is used. A further study of this problem has also brought out the fact that there are a number of anti-knock substances, such as lead tetra ethyl, which will permit a much greater increase in compression than benzol, and that some of these are required in such small quantities and can be produced sufficiently readily so that their use in gasoline will probably soon become general. Automobile engines are being designed to take advantage of this improvement as soon as the problem of producing the fuel is fully solved, and this will result in a considerable increase in the mileage per gallon.

A gasoline engine problem of special interest comes

from the reduction of power of airplane motors when used at high altitudes. This is caused by the lightness of the air at these levels and the consequent lower compression pressure and smaller weight of the air fuel mixture taken into the engine during each revolution. The seriousness of this problem during the late war arose out of the fact that most of the fighting was done at high levels, and that the aviator who could get above his opponent had the advantage.

The rule-of-thumb method of improvement, based on trial and error, is hardly a safe one to use in aeronautical development, as the errors are likely to result disastrously for the pilot of the experimental plane. This problem was, therefore, first studied by mounting an engine on a truck, taking it to the top of Pike's Peak, and making complete tests at every added 1000 feet of elevation. However, this was a troublesome way to try out every improvement, and the maximum height was far below the highest elevations to which airplanes were climbing, so a shed was constructed from which the air could be partially exhausted to correspond to any desired elevation. The engines were then tested in this shed with all the controls brought outside so that the observers could carry on their work without the discomfort of being in a rarefied atmosphere.

The early methods of improving the power at high altitudes resulted in making the operation of the engine much more difficult when near the ground. A study of the situation on the basis of the theoretical background of the subject showed that the only real remedy was to compress the air at high altitudes before sending it to the engine cylinders. Then various types of compressors were tested, and their design improved as the weak points

were revealed. Finally, a rotary compressor, or supercharger as it is called, was evolved, which could be started when the airplane got into high altitudes, and which was driven by the exhaust gas from the engine. While this was not completed in time to be of much use during the World War, it is interesting to note that immediately after its adoption new world's records for altitude were made by American aviators, and supremacy in this line has remained here practically ever since.

The space available has permitted the use of only a few illustrations of the progress in the three branches of power development due to scientific research. The method always includes the same steps. First, as a rule, comes the replacement of theories and guesses concerning what actually goes on in any machine or process by actual facts determined by experiment, and several chapters could be written describing the ingenious methods and instruments devised to secure this information. Next comes the development of an adequate theory of operation based on these facts and on the laws of physics, chemistry, and mathematics which apply to the case, and this is followed by the use of this information as a guide for research into all possible improvements. When thinking of the progress in steam and hydraulic power in the last twenty years and recalling that the first successful internal combustion engine was built less than fifty years ago, one may well wonder what the next half century will bring forth.

CHAPTER IX

RELATION OF RESEARCH TO HIGH SPEED MACHINERY AND THE MECHANICAL WORKING OF METAL

J. A. Hall

In addition to increase in power and efficiency of engines and turbines, reduction in cost per unit of output is of great importance, and increase in speed of operation has been one of the big factors along this line. The modern American automobile engine runs at a maximum speed of 3400 to 3600 revolutions per minute, and a recent foreign model is said to run at 6000, while the corresponding speed of their predecessors of only fifteen years ago was but 1000 to 1200. The importance of this change lies in the fact that the modern engine, by running three times as fast, gives three times as much power as the slower unit of the same size, or for the same power output it can be correspondingly smaller. Similarly the 40,000 horsepower steam turbine of the present day power plant takes less space and weighs much less than the 2500 horsepower steam engine of twenty years ago. However, this turbine probably runs at 1800 revolutions per minute as compared with less than one hundred for the engine.

In fact, high speed is the outstanding characteristic which differentiates modern practice in the design of all kinds of machinery from that of a quarter century ago, and the resulting greater output without a correspond-

ing increase in raw material requirements and investment costs has been an important factor in modern industrial progress. In this development many new problems have confronted the designer, and progress would be very slow if it were necessary to depend on his mechanical ingenuity, checked only by a long process of trial and error, to provide the correct solution. Scientific research has been of particular value in shortening the time required for the change and eliminating a great deal of waste of material and effort.

A. *Bearings*

The rubbing of any shaft against its bearing increases directly with the speed, and this immediately raises the problem of more rapid wear, higher temperature, and greater friction losses. These troubles now seem to have been largely eliminated by lubricating arrangements through which a thin film of oil is continuously drawn between the rubbing surfaces so that they never come into contact with each other while the machine is running. The thickness of this film in some places may be but a fraction of that of a sheet of newspaper, and still prevent metal to metal contact even when subjected to very high pressures. As a result of thus floating the shaft on oil, the friction losses are very small, and there is practically no wear at all as long as the oil film remains unbroken.

Partial lubrication is the term which should be applied to the oiling arrangements of many bearings in which there is occasionally some metal-to-metal contact. This was practically the only type of lubrication in old style machinery, but it would be fatal to a modern high speed shaft. The use of the proper oil and its application in

such a way as to maintain a complete film continuously between the rubbing parts was not fully appreciated until long after the researches made by the English scientist, Beauchamp Tower, in the early 1880's into the conditions of perfect lubrication. Now this practice has become so general that 100-mile automobile trips, in which the engine may make a quarter of a million revolutions without stopping, are commonplace, and large turbines in central power plants frequently run continuously for several months, making many hundred million revolutions in that time. In fact, the engine bearings generally wear out because of the wear and tear of starting rather than the amount of time of running, and there seems no reason why the turbine should ever wear out, the only reason for depreciation charges being the danger of its becoming obsolete.

The classic research on this subject was the work of Tower noted above, and this was followed by a complete mathematical analysis of perfect lubrication on the basis of the laws of fluids in motion by an English mathematical physicist, Professor Osborne Reynolds. Further mathematical researches into this subject helped to simplify Reynolds' work, and these in turn were verified by further experimental investigations, so that the relations between many of the factors involved were reduced to definite equations. This work has now become the foundation upon which the great achievements in applying perfect lubrication to modern machinery are based, and it is therefore interesting to note that at the time, the work of Tower and Reynolds was considered of great interest but not of practical application.

The mathematical analysis referred to above showed that if a block were drawn along another metal surface

which was covered with oil, the block would tip back slightly due to the formation of an oil film under it in the shape of a wedge, and this proved to be the natural form of such a film. The application of this discovery is responsible for the great advance in the design of thrust bearings during the past few years. In the Kingsbury thrust bearing, which is probably the best example of this practice, a collar which is fastened to the shaft bears against pivoted blocks which can tip to any angle to suit the oil used. When this bearing runs in oil it is practically impossible to break down the film separating the collar from the segments, and as a result, there is practically no wear and very little friction. In the case of the 70,000 horsepower vertical turbines of the Niagara Falls Power Company, a single bearing of this type carries the weight of all the rotating parts amounting to 1,250,000 pounds. Before the development of such bearings, turbines of anything like this size were impossible. Now, however, these bearings are not only being used in such places, but are replacing the older forms of thrust bearings on shipboard and in many other places because of the large saving in space and weight, the reduction in friction losses, and the greater reliability in operation.

It is practically impossible to maintain perfect lubrication in many bearings, and, even where it is, the shaft and its bearing generally rub against each other for a few moments while starting up before the oil film is established. This causes wear, and some bearing metals stand up much longer under this rubbing than others. This difference led to a study of these metals under a high power microscope which showed that they were not homogeneous, but were built up of different kinds of crystals. Further investigation showed that the metals

which wore the longest were those which combined a very hard crystal which stood out and took the wear, with a soft crystal which tended to retain some of the oil during the time when the machine was not running. It was also found that some bearings which were not standing up had the crystals near the surface badly crushed, showing that dull tools had been used in machining them. Thus the study of the microscopic structure of metals, or metallography as it is called, which started as a purely theoretical scientific research, has become of great practical service in the development of the best metals for bearings.

In many places where perfect lubrication cannot be maintained, the friction losses are apt to be great and the wear excessive, but this difficulty can frequently be overcome by replacing the oil film by a series of steel balls or rollers. This is not as simple as the above statement indicates, as may be seen from the fact that while ball and roller bearings have been used for heavy loads at slow speeds for many generations, it was only after a scientific research into the whole problem that reliable operation at moderate speeds was made possible. Now, however, bearings of this type are operated under a great variety of conditions of speed and load, with the consequent reduction in friction losses and with the elimination of practically all wear.

In this case, the pioneer work was done in Germany by Professor Stribeck, who started with a mathematical study of the laws of elasticity as applied to the deformation of balls or rollers when pressed against flat or curved plates. The equations developed in this study were then checked by experimental research, using specimens made of hardened steel. One important contribution of his work

was the discovery that the strength of the metal used was a minor consideration when compared with uniformity of hardness and size of the balls or rollers, and the application of this information has helped greatly in making this type of bearing a success. Stribeck's equations showed a maximum allowable variation in diameter of the balls in a set, to be a tenth of a thousandth of an inch, and now these balls are made commercially with an outside variation of one-half of this amount. Some appreciation of this limit of accuracy may be gained from the comparison with the thickness of a sheet of newsprint paper, which is about three-thousandths of an inch. As a result of this study, the allowable loads under various conditions and the limitations of operation were determined, so that such bearings are found in large numbers in all kinds of modern machinery.

The attempt to find out just what is happening in bearings under load has made up a large part of the scientific research in this subject to date, and even now what is known seems very small when compared with what is still largely a matter of speculation. It is particularly interesting to note the large contribution higher mathematics has made in many of these investigations, as this gives some indication of the saving which is possible if the fundamental laws involved are sufficiently well known so that the experimental work can be suitably combined with mathematical analysis.

B. Vibration

Increased trouble from vibration in machinery, due to high speed operation, furnishes another problem which cannot easily be solved by rule-of-thumb methods. Many

motorists have some acquaintance with this difficulty because their automobiles become uncomfortable to ride in at certain speeds due to vibration of the engine. In some cases further increase in speed causes greater discomfort, while in others the vibration dies out as the car goes faster. These illustrate the two principal sources of this trouble as the latter was due to the engine passing through what is known as a critical speed, while the former type was due to lack of balance.

The problem of balancing machines is not a new one, as it has long been customary in cases where this seemed of importance to mount the shaft holding the flywheel, pulley, or similar part which might be out of true on two parallel rails and roll it along to see if in any position one side was heavier than the other. In this way the part tested was put in what is called "static balance." Such a process is decidedly inadequate in high speed machinery, as an unbalanced section at one point on the shaft may be equalized by a similar unbalanced section at another point when tested by the above method, and yet cause violent vibrations in the machine when brought up to full speed. In this case the rotating parts are not in "dynamic balance."

This problem is one of particular difficulty as lack of dynamic balance can be determined only when the machine is running and then it is difficult to determine the location of the balancing weights necessary. The first solutions came from study of the forces involved, and this resulted in changes in design so as to compensate for unbalanced forces as exactly as possible. While this was of help, it was not good enough for the highest speeds desired, so after considerable study of the factors involved, several machines have been developed which

can be used to measure the extent of lack of balance, and to determine the location of the proper weights to compensate for it. Practically all heavy high speed rotors are now tested in this way before the machines into which they are to go are finally assembled.

Critical speed vibration has a somewhat different origin. Just as each tuning fork oscillates a definite number of times per second and only requires the infinitesimal force of sound waves of the proper frequency to set it in motion, so every shaft has its natural period of vibration depending on such factors as its size and the location of its supports, and if this coincides with the rotation of the shaft the slightest out of balance may set up such violent vibration as to wreck the machine. The speed required is generally very high, but many modern machines operate above the first or lowest critical speed of their shafts; so the study of this problem has become very important.

The first method of overcoming this evil is to put the rotor in both static and dynamic balance as accurately as possible so that the forces tending to cause vibration are reduced to the minimum, and this helps particularly if the machine passes through the critical stage while being speeded up to or slowed down from its operating speed. This balancing can hardly be done sufficiently well as yet to permit regular running at the critical speed, so a study of factors governing it has become of great importance. Here mathematical research based on the laws of elasticity, rather than experimental investigation, has furnished the solution of the problem, and as a result it is now possible to design new high speed machinery directly without going through the expensive "cut and try" method of building experi-

mental units to see if the critical speed has been avoided.

C. Fatigue of Metals

Fatigue of metals is the term applied to the well-known fact that machine parts will break if subjected to a large number of repeated applications of a load much smaller than that which can be carried indefinitely as a constant steady pull. The title indicates that weariness due to hard work may be the cause of fracture, but whether this is true or not, the effect is increasingly serious in modern machinery where the repetitions of stress may reach enormous figures. For instance, an automobile engine in a normal running life of 100,000 miles will make about 250,000,000 revolutions, and it is important that the connecting rods, crank shafts, and similar parts be as light as possible and still not break after a few million repetitions of load.

The studies into this problem have consisted largely of repeatedly applying known loads on specimens until fracture occurs. One of the most extensive investigations of this sort has been carried on during the last few years at the Engineering Experiment Station of the University of Illinois, where steel specimens having different compositions and heat treatments were tested, in some cases the number of reversals of stress exceeding a hundred million.

This investigation seems to have established the fact that there is some allowable stress for every material which may be repeated indefinitely without danger, but that as the load is increased above this point, fracture will occur with a smaller and smaller number of applications. This is a fortunate discovery for the builders

of high speed machinery, as any part which is strong enough for ten million repetitions of its load will continue to stand up under a billion. On the other hand, the allowable stress varies for different materials, and the number of these used in machine construction is very large. For instance, the properties of steel compounds vary with comparatively small changes in the percentage of different elements combined with the iron, and also with the temperature and the rate of cooling in the heat treatment used. As a result, the problem of determining the safe loading for each alloy is only partly solved.

To the scientific investigator, the reason for what happens is fully as important as the results of the experiments themselves, because the extent of the laboratory work can be greatly reduced if the laws governing the phenomena are fully understood. The old opinion concerning fatigue failures was that metal crystallized under the repeated stresses, and that the growth of these crystals was the cause of the loss of strength. The reason for this idea was that metal always has a coarse structure at fractures of this sort. However, the study of the microscopic structure of the metal, after polishing and etching the broken section, showed that it was just as fine as before subjected to stress at all. This method of investigation also proved that practically no metals were uniform, but were made of crystals or groups of crystals of varying strength. This led to the present theory of repeated stress failure, that the weaker of these crystals are overstressed, and cracks start which gradually extend around the stronger groups until the piece is so weakened that it fails.

Any local weakness from which cracks might start

The Laue pattern obtained by passing a beam of X-rays through a crystal of barium sulphate. It was such a photograph as this that gave the first clear evidence of the undulatory character of X-rays.

will reduce the resistance to this type of load, provided the above theory is true; so tests were made with specimens which had small scratches on them, and these uniformly broke at much smaller loads or fewer repetitions than the carefully polished pieces. Other specimens having sharp corners or similar sources of weakness also showed themselves much inferior to those which were straight or had rounded corners. As a result, these tests not only helped to verify this theory of repeated stress failure, but also furnished valuable information concerning the design of parts for repeated loads.

When metal is overstressed, there is always a slight rise in temperature due to the particles slipping on each other, so the further investigation of the above theory led to the study of the temperature of specimens when rapidly subjected to a number of repetitions of load. Very sensitive instruments were required to get any results, but their use showed that a slight temperature rise occurred as soon as the safe load was passed, and that it increased with heavier loads. This not only gave another verification of the theory, but it also furnished a much more rapid method of determining the maximum safe load than had previously been used.

A great deal of the research work on fatigue of metals was first undertaken to help solve some of the problems of the airplane. On these machines every part must be as light as is consistent with safety, and the only way to determine the allowable load in many cases is to find out the effect of repeated stresses. With increased operation speeds, however, the information secured concerning both the number of stress applications at different loads before breaking will occur, and the reason for such

failures is proving of increasing value in the design, not only of airplane parts, but of all kinds of machinery.

The preceding discussions have taken up the contribution of scientific research to the solution of three of the problems which have arisen out of or have been made much more serious by the increased speed of operation of modern machinery. Many others could be described if space permitted, such as the studies which resulted in the reduction of the stresses caused by centrifugal force tending to burst the rotors of large high speed turbines, or in the changes in the shape of gear teeth and the greatly improved methods of cutting and testing them to secure satisfactory automobile transmissions, electric locomotive drives, and turbine reductions.

The result of all these discoveries has been the satisfactory use of high speed power apparatus and other kinds of machinery, with the corresponding larger output and lower capital charges which result from the reduction of weight required for a given capacity. If it had been necessary to depend on the practical designer, without assistance from scientific research, these improvements would have developed much more slowly and at greatly increased cost. This is because many new problems were introduced which were not covered by previous experience, and the acquisition of the required knowledge by the method of trial and error would have been a long and expensive process.

METAL WORKING

A. Development of New Machines and Processes

During the past twenty-five years the United States has led the world in the building of machines for the cut-

ting and forming of metals, or machine tools as they are called. Most of the improvements have been along the lines of increasing speeds, developing new processes, and making the machines more nearly automatic and more nearly foolproof, so that the output per worker can be increased. In fact, this country is probably supreme in the development of labor saving devices, not only in machine tools but in all kinds of machinery, although the reason for this is not mere spontaneous Yankee ingenuity, but that ingenuity stimulated by economic pressure due to an inadequate supply of highly skilled artisans combined with the highest wage rates of any industrial country in the world.

The pressure has become so great that much of the inventive genius of the country is now engaged in this field, and improvements are brought out so frequently that machine tools for production or repetitive work quickly become obsolete. This condition is probably the reason for the statement often made that the machine tool industry is never flat for any length of time because something new is always being put on the market which the other manufacturers cannot afford to do without. As a result of this intensive effort, sewing machines, automobiles, and any other products, which are sold in large quantities and require a considerable amount of machine work in their manufacture, have almost continually declined in price during the last twenty years in the face of very great increases in the cost of labor.

Many types of automatic machines are now made which receive their raw materials in the form of bars or castings, and deliver their product completely finished, even when many complicated operations are required. A number of these machines can be taken care

of by one operative, his duties being to see that new stock is always ready to go into the feeding device, and to adjust or replace the cutting tools as they wear. In this case, no essential change is made in the method of manufacture except that many operations are combined in one machine, and the mechanism for handling the work and controlling the cutting tools is made as nearly automatic as possible.

Another type of improvement is found in the adaptation of methods used in other kinds of work, or in the development of entirely new processes. For instance, stamping or pressing flat metal sheets into special shapes by the use of properly shaped punches and dies has long been common practice where thin pieces or soft metals were used, but the process is now being rapidly extended to the use of heavy steel plates in the manufacture of parts which were formerly made from iron or steel castings. This generally results in a considerable saving in weight for equal strength and a great reduction in production cost, provided the expense of the dies can be spread over a sufficient number of parts. The low priced lightweight automobile owes a great deal to the extension of this process.

Many additional illustrations could be given to show how the mechanical engineer, by developing labor saving machinery and processes, is increasing the output and hence the wealth produced by each worker, but these of themselves do not show the value of scientific research as an aid in this development. The mechanical ingenuity of the engineer is probably a more important factor in the design of automatic machinery at least, but if this quality is not supplemented by a good background in the fundamental principles of mechanics and

a knowledge of what has already been found out by research, the development is usually slow and expensive. Examples of the latter type of information may be found in the work done on lubrication and bearings mentioned in an earlier section, and on the improvement of materials used in construction to secure greater strength, hardness, or other desirable qualities.

Many builders of machinery maintain their own experimental laboratories, not so much to carry on research work on basic subjects of interest to all, as to test all suggested improvements and determine relative values by exact standards of measurement. This has replaced the old conference method where all the experts gathered to watch the new machine in operation, and then each expressed his judgment as to its relative worth, this opinion generally being influenced by many factors entirely apart from the particular improvement being studied. While this may not be research of the "high-brow" variety, some really scientific and very valuable work is being done in these laboratories.

Another type of research of value to all manufacturers in the same line is the attempt to determine the relation of the various factors involved in a given process so as to put it on a scientific basis. The studies of welding carried on under the supervision of the American Welding Society form a good illustration. Both oxyacetylene and different forms of electric welding had been developed rapidly, but the product was not uniform and, therefore, no one would place much faith in welded joints. After an experimental investigation of the effect of all the different variables on the strength of the joints, the best methods were chosen. A little later a number of welded tanks submitted by eight dif-

ferent manufacturers were tested for leakage and bursting pressure, and every one proved superior to the best riveted tank. This method is cheaper and quicker than riveting, and now that it has become equally reliable, its use is being so greatly extended that even the welded ship may soon become a reality.

B. Laws of Cutting Metals

The function of most machine tools is to cut or pare metal from castings or forging to reduce them to the form desired, so the laws of metal cutting must be determined before such machines can be put on a completely scientific basis. Any consideration of this subject generally starts with the monumental research work of the late Fred W. Taylor, who is better known to this generation for his writings on Scientific Management. When Taylor became a machine shop foreman at the Midvale Steel Company in 1880, every mechanic chose his own cutting tools and determined for himself the best method of operating his machine, and the tools and methods used by different men on similar jobs were never exactly alike. Taylor decided that there was but one shape of tool and one correct method of operation which would give the greatest production on any given type of work, and convinced his supervisors that the increased output which would result from definite knowledge of these facts would more than pay for the expense of the investigation.

After an analysis of the operation of lathes and boring mills on which most of the work under his supervision was done, he found that there were twelve elements which might vary. He next chose, as the yard-

stick against which to measure the effect of each variable on the problem, the speed of cutting which would leave the tool too dull for further use at the end of a twenty minute run. Several cutting tools were made up exactly alike in every particular, and the first was run under the desired condition at a certain speed. If it was still in good condition at the end of twenty minutes, a second one was tested at a faster rate, and so on until the maximum speed for a run of this duration was determined. Similar groups of runs were then made where only one element of operation or shape of tool had been varied, and so on until the effect of varying each of the elements had been determined.

He soon found that the cutting speed and therefore the output could be increased over 30 per cent by a modification of the shape of the tools as commonly made by the mechanics of that day. The study of the relative value of fine chips at high speed and coarse chips at low speed showed that, contrary to usual practice, much more work could be done using the latter combination. This involved much greater pressures between the tool and the work, and resulted in a demand for heavier and more rigid machines. Other improvements followed in rapid succession as the tests which were expected to last six months at the Midvale Machine Shop were widened in scope and continued for twenty-six years in different factories by Taylor and his assistants, the improvements which were made amply repaying the cooperating companies for the cost of the investigations.

During this period over 30,000 complete tests were made and recorded, the data plotted, and the relations between the different variables reduced to mathematical equations. Later one of Taylor's associates, Mr. Carl

Barth, combined these equations on a series of slide rules, one for each type of machine, so that the best combination of the different factors could be easily determined by any shop clerk. In 1906, when Mr. Taylor became president of the American Society of Mechanical Engineers, he presented as his address at the annual meeting of that society the results of all his research work on this subject, thus for the first time making public for general use the great discoveries he had made. This paper, "On the Art of Cutting Metals," fills a good-sized volume, and has become the classic in this subject.

Some of the most important discoveries made by Taylor were really by-products of the original investigations. For instance, in the late 1890's, he ran some tests to pick out the best of a number of varieties of the new so-called self-hardening or high speed steels, which, because of their chromium and tungsten content, could be used at a much higher temperature and speed than ordinary tool steels, and still maintain their hardness and cutting edge. As the results of these tests were not consistent, he felt that the method of hardening recommended by the steel manufacturers might be at fault, so an investigation of the hardening of these steels was immediately begun, the temperature to which the tools were heated varying by fifty degree stages from a very low level up to the melting point of the steel. This brought out the amazing fact that tools heated five hundred to nine hundred degrees above what had previously been considered the proper temperature, that is, practically to the melting point, could do from twice to four times as much work in the cutting tests. This scientific investigation resulted in the development of the Taylor-White tool steels which did more to revolutionize the

machine tool industry than any other discovery in that generation.

While Taylor's investigations were the most extensive and the most valuable that have ever been conducted in his field, they only covered roughing cuts on machines using similar types of cutting tools, such as lathes, boring mills, and planers. Studies on different machines by other investigators helped to increase output, and have done much to put the design of these machines on a more scientific basis by giving definite information concerning the power required and pressures exerted during operation. On the other hand, little work has been done as yet on fine, or finishing cuts, or on new materials with different properties which are constantly coming into use in machine construction. The elements of the cutting problem are so complex that it has been impossible to gage at all accurately what the relations between them will be under changed conditions, so at present tests must be made to cover each new combination of this sort. Some day the universal laws covering all factors will be derived, and in the meantime, each new research is helping improve present practice as well as contributing to this ultimate goal.

C. Control of Materials

The factors influencing the strength, hardness, and other properties of materials are fully as complex as those involved in cutting metals, and it is, therefore, equally difficult to reduce this problem even approximately to definite laws, or to make use of the mathematical methods which are of such great service in investigations where the principles of mechanics, hy-

draulics, or heat are involved. Because of the complexity of this problem, if one or two pieces out of a large number of similar parts break, the remainder doing satisfactory service, the practical shop man is apt to consider it an "act of God," like having a building struck by lightning, and does not worry unduly unless it happens frequently. In a factory where the scientific method prevails, on the other hand, each failure is carefully investigated, all pertinent facts recorded, and the broken piece probably examined in the laboratory. The continual collection of such information has resulted in some very valuable discoveries.

A company, building automatic sprinklers used in the fire protection systems of many buildings, was troubled by the fact that once in a great while the brass plates or diaphragms in some of these sprinklers would break, permitting a lot of water leakage with resulting property damage. This only occurred in damp places, but thousands of units built to exactly the same specifications had been in similar locations for fifteen or twenty years without giving trouble. The research engineer found that the brass which failed was badly corroded, while that in the good sprinklers was hardly corroded at all. The two were alike in chemical composition, but a microscopic examination showed that the plates which failed had a much coarser crystalline structure than the others.

Studies were then made of the microscopic structure of brass from a special series of plates rolled and annealed under different known conditions. These samples were also subjected to accelerated corrosion and fatigue tests. The investigation showed that this particular alloy contained two kinds of crystals, one of

which tended to corrode much more than the other. The rolling of the plates to reduce them to the proper thickness causes large internal stresses, and if these stresses were not removed by proper annealing, they caused the metal to crack because of the unbalanced structure after the selective corrosion had gone on for a sufficient time. The proper methods of rolling and annealing to secure the desired internal structure were then determined by further experiments, and a continual check on this quality was maintained from then on by taking a microphotograph of a sample from every lot of plates.

Such scientific studies have helped to solve many of the obscure difficulties with metal parts, so that now the microscopic study of specimens polished and etched to reveal the internal structure is proving of as great value to the engineer in the control of the materials he is using, as it is to the metallurgist in the development and manufacture of these materials. For instance, some brass pipe used in a low pressure water system split open, and a careful examination, both of the system and of the pipe, failed to reveal the cause until a microphotograph showed that the metal had not been properly annealed to remove the internal stresses. A number of years ago on the construction of the new water supply for New York City, a manganese bronze rod used for a ladder support broke off in a workman's hand, and immediate investigation revealed many others in nearly as bad shape, while some of those on the storeroom shelves had broken without being under any load whatsoever. These rods were entirely satisfactory from the standpoint of strength and ductility when delivered, but a belated microscopic inspection revealed heavy internal rolling stresses unrelieved by proper annealing. In both

of these cases the material would not have been accepted if this quality had been investigated.

The use of the microscope is fully as important in the study of steel as it is in the nonferrous metals. While many special steels have been developed to meet the demand for greater strength and toughness in proportion to the size of machine parts, most of these new alloys have to be properly heat-treated to give the desired qualities, and this results in a change in the size and kind of crystals making up the material. The use of the microscope, therefore, seems indispensable in any research studies into the best method and temperature to use in the treatment of steel. It is also of great value in checking routine shop methods, or in investigating failures of parts in operation, as any deviation from the desired internal structure of the metal indicates that the heat treatment has been at fault.

While the microscope is essential for investigating certain types of problems, machines for measuring the strength of metal specimens by testing them up to the breaking point are probably more important, if adequate control is to be maintained of the materials used in construction. Furthermore, the ability to resist shock is not always proportional to the strength of a metal, so impact testing machines have come into use where the energy given up by a swinging pendulum in breaking a properly located specimen gives a measure of this quality. Other important and somewhat related qualities which are desired in many materials are hardness, toughness, and resistance to wear, and one of the instruments, of great value for determining the extent to which various metals possess these qualities, uses a small hardened steel ball which is pressed against the piece to

be tested with a known force. The diameter of the indentation made by the ball gives an indication of the hardness of the material. A number of investigations have determined fairly well the relations between the hardness figures given by this method and the strength and ductility of various metals, and as a result this simple and convenient test is frequently used alone as a check on the properties of special steels particularly after heat treatment, one reading being sufficient to show whether the metal is too hard and therefore brittle, or too soft and therefore not sufficiently strong.

The instruments and methods mentioned are but a few of those which have been devised for use in studying the properties of materials, and then in controlling them so as to secure the uniformity desired. The results in the manufacture of automobiles, where, in spite of hard usage and the shock of high speed driving over rough roads, the parts generally wear out but rarely break, may be taken as one record of accomplishment to date.

D. *Fine Measurement as a Factor in Production*

How long is an inch? In the old days when the king's foot was the standard of length, the exact distance included in a twelfth part of this amount was not a serious matter. Conditions had greatly changed, however, by the time the United States entered the World War, when production of army rifles had to be stopped for several days to await a definite answer to this question.

A requirement of long standing in the manufacture of this type of war material is interchangeability of parts, that is, if ten rifles are taken apart and the pieces put

into one pile, it should be possible immediately to reassemble them into the same number of complete units using the first piece picked up of each kind. Three different companies were engaged in making U. S. Army rifles, and while those made by each manufacturer, if kept by themselves, met this test, it could not be done with thirty of them, ten coming from each factory. In other words, an inch was not the same length in these three factories, and while the variation was considerably less than a thousandth part of this unit, it was enough to prevent interchangeability of many of the closely fitting parts in a modern rifle.

The application of the principles of rifle manufacture, interchangeability of parts and assembly without special fitting, to all kinds of large scale production is very common in this country, and it is now generally known in most foreign countries as the American System. It is because of this system that automobiles and other machines produced in large numbers can be turned out at a lower cost, in spite of the high wage rates, than those made abroad under the old method of individually fitting parts together. One difficulty with the interchangeable method is that parts have to be made exactly to size within the narrow limits specified, and, as some pieces may be made in one factory and some in another, it is important that all use exactly the same standard of length. Furthermore, the gages used in inspecting the parts to see that they are between the specified limits need to be measured much more exactly than the pieces themselves, and finally, the dimensions of the standards by which the gages are tested require a still finer measurement.

Purely mechanical methods are no longer adequate

for ascertaining the dimensions of reference standards used in the production of inspection gages for fine manufacturing, and, furthermore, the legal standard of length in this country, which consists of a steel bar having two fine lines on it exactly one meter apart, is not entirely satisfactory on account of possible slight changes in the metal over long periods of years. One distance which never changes, and can, therefore, be used as a definite standard of linear measurement is the wave length of light, and, as this distance is between one and three hundredths of a thousandth of an inch, depending on the kind of light used, it is possible to measure very small variations in size by use of such a unit.

Imagine a mirror so slightly silvered that half of the light striking it is reflected and half transmitted to be placed in such a relation to a second mirror that its surface is struck by the transmitted light and reflects it back against the first mirror. If the latter light waves reach the silvered surface of this mirror in phase with those striking it for the first time, that is, with "crests" and "hollows" corresponding to each other, the intensity of light is doubled, but if "crest" matches with "hollow," the two neutralize each other, the result being a dark line or spot on this surface. If the second mirror is moved so as to increase the distance between the two, light and darkness alternate with each other. The distance through which this mirror is moved to cause one complete cycle from light to dark and back to light again is half of the wave length of the light used. This interference of light waves is the principle made use of in the instrument called the interferometer which, combined with suitable apparatus, is used to measure distances where the most accurate results are desired.

The discovery of these properties of light must be credited to the research work of the physicist, but many additional studies were necessary to make possible the application of this knowledge to the problem of fine measurement in industry. Much of this work was done at the laboratories of the United States Bureau of Standards, and, as a result of their work, one American concern is now manufacturing blocks or gages which are guaranteed to be within 1/100,000 of the dimension stamped on them, so that they can be used as absolute reference standards. Another concern, which specializes on fine measurement, has had reference scales which are accurate to the millionth of an inch made by the light wave method of the laboratory of the Bureau. The measuring machines used by this company give definite observations to the hundred thousandth of an inch, and these reference scales, read through a microscope, are used in setting the machines so that continuous accuracy is assured. In such ways as these the development of the American System of interchangeable manufacture is being put on the sound basis of exact measurement.

E. Stress Analysis by Light Waves

The knowledge of the properties of light has been of practical service to industry in many ways aside from fine measurement. The element of risk in the manufacture of large lenses and other glass pieces which have to be cut or ground has been greatly reduced by inspecting them with a beam of light before starting this work. Frequently cooling strains remain in glass even after annealing, and these may cause a crack when some of

the surface has been ground away, thus ruining the piece and making all the work on it a total loss. Glass having internal strains distorts light, and the amount of this distortion depends on the wave length, so a beam of white or similar light, which is made up of a combination of wave lengths, will be broken up into all the colors of the rainbow when passed through such a piece. This immediately indicates that the glass requires further annealing, and grinding is postponed until the light tests show that all these internal strains have been removed.

Not only can undesirable internal strains be revealed by the use of this property of light, but it can also be used to study the distribution of stress due to the known external loading of a piece of otherwise unstrained glass, celluloid, or similar translucent material. This is due to the fact that the stress or force acting at any point in this material is proportional to the internal deformation or strain at that point, and the presence of this strain is revealed by the distortion of the light passing through it. The intensity or amount of the internal stress can also be determined by the use of proper apparatus. The importance of this development arises from the fact that the stress in steel, as in glass or celluloid, is always proportional to the strain, and, as these ratios are known for all three materials, the distribution and extent of the stresses in a steel piece or structure can be determined by the use of "polarized light," as it is called, in the study of a celluloid model.

Many machine parts are so complicated in shape, or are loaded in such ways, that it is very difficult to calculate the internal stresses or forces for which they should be designed. Moreover, simply making them

heavier is not a sure remedy, as the addition of metal might make a piece weaker rather than stronger if the enlargement is not made in exactly the right place. In the study of such parts as these, the use of polarized light on celluloid models becomes of very great value.

One extensive study has been into the stress distribution in the pinions of electric railway motors. These pinions are heated up and shrunk onto their shafts, so the internal stress is caused by a combination of this pressure and the force on the teeth due to the power being transmitted. Full size celluloid models were made up, and forces applied both on the inside of the gear and on one of the teeth corresponding to different shrinkage pressures and rates of power transmission. In this way the complete distribution of stress throughout the pinion was analyzed, and its amount for the maximum load condition determined, with the result that the whole problem was taken out of the field of vague assumption and was put on the basis of exact knowledge.

This method is now being applied to such diverse problems as the analysis of the pressures acting in the cutting of metals on the one hand, and the determination of the force distribution in the decks of destroyers due to different kinds of construction on the other. While the process is so new that much is still to be learned about its use, it is becoming an excellent tool for carrying on research into many heretofore obscure problems in design and construction. Thus the knowledge of the properties of light is here, as in fine measurement, becoming a valuable aid to mechanical engineering development.

The metal working industry owes a great deal to the mechanical ingenuity of the inventor who made very

large contributions particularly to its early development. It is, therefore, interesting to note the extent to which his work is being supplemented and even supplanted by scientific methods in the analysis of problems and research investigations in determining the fundamental facts on which their solution is based.

CHAPTER X

PROGRESS IN TEXTILE MACHINERY—AN EXAMPLE OF PROFITABLE SCIENCE

J. A. Hall

A. Development of Machinery and Processes

While the spinning and weaving of textile fabrics is one of the oldest arts known to man, the tools used and the methods generally followed only one hundred and fifty to two hundred years ago had changed little if any since the days of King Tut, and perhaps since the reign of some unknown monarch many thousand years before. Cloth was woven on hand looms where the energy required for all the operations had to be supplied by the weaver, while the quality of the yarns used in the cloth depended entirely on the skill of the spinner. With the limitation in the number of people available for this work plus the high cost in labor hours per pound of output, it is little wonder that all the womenfolk of the family had to spend most of their spare time making the yarns from which their homespun garments were made.

About five years before the beginning of the Revolutionary War the first successful spinning machine, known as the "spinning jenny," was invented in England, and this was followed by several other types in the next few years. These were superseded by the invention of the "mule" by Crompton in 1779, receiving its

Interborough Rapid Transit power plant, showing a modern steam turbine in the foreground and an old Manhattan engine in the background.

name from the fact that it was a hybrid combining the best points of its predecessors. The invention of the power loom in 1785 by Cartwright, together with the development a few years earlier of the steam engine by James Watt, the instrument maker of the University of Glasgow, completed the round of great inventions which ushered in the factory system.

The development of these new machines was due principally to the mechanical ingenuity of their inventors, rather than to their use of scientific research, and the same must be said of most of the later improvements, through which the machines have been made much more nearly automatic, and great increases in speed attained. A great deal of experimental investigation of at least the "trial and error" variety has been required during this evolution, which has resulted in such innovations as the automatic loom, twenty-four of which are often run by a single operative, or the jacquard loom which is such a triumph of mechanism that it can be used to weave rapidly and automatically elaborate designs in many colors.

The steady improvement over a long period of years has brought most forms of textile machinery to a stable condition where great changes in design are not generally expected, so the problem of operation seems now of major importance. The solution of this problem has depended in the past, and still does to a large extent, on the opinion or judgment of the men skilled in the art. The raw fibers were classified by feeling them or testing them with the fingers, while the finished fabric was judged by visual inspection and perhaps by tearing it or breaking a hole in it over one's thumbs. Scientific methods of measurement from which the personal equa-

tion was eliminated were rarely used. While the best men may produce exceptionally fine goods under this system, the results cannot be made uniform for all men, and possibly the best work can be improved, so scientific research is being used to determine the factors involved in the problem, and to put them on a basis of fact instead of opinion.

Men accustomed to working nearly homogeneous materials, such as iron or steel, generally fail to realize the complexity of this problem. Millions of fine fibers are required to make a pound of cotton yarn or thread, and in any handful taken from a bale of the raw material these fibers vary greatly in many ways, such as length, diameter, strength, and natural twist or spirality. Furthermore, these characteristics are not the same for samples taken from different bales, particularly if the cotton was not grown under identical soil and weather conditions, and, because of the latter alone, variations exist in the product of the same field in successive seasons. The scientific study of this problem has dealt largely with developing methods of making quantitative measurements of these variables, and determining their effect on the strength of the finished goods and on the percentage of waste in process. These studies have already developed to the point where many of the most successful cotton buyers and classers are making use of them in choosing the raw material which can most advantageously be used in their mills.

Similar studies of silk fabrics showed that their strength and elasticity, and the strength of the natural gum coating which gives them their luster, were the characteristics of particular value, so instruments and a method of testing were devised to measure these quali-

ties. The serigraph test, as this is called, is now used to classify the silk purchased by American concerns into different kinds according to its suitability for the various lines of manufacture. This development has proved so satisfactory that, shortly after its adoption, one of the men engaged in this research work was sent to the Orient to instruct the Japanese and Chinese in the best methods of preparing the raw material for the American market.

In addition to the control of raw material, the processes of manufacture are being subjected to scientific study. The facts of operation are determined by methods involving objective measurement, and are then made part of the recorded knowledge of the subject, instead of depending solely on the judgment of some skilled overseer or mill superintendent for the selection of methods and machine settings to be used. As the result of such studies and a proper choice of cotton so as to secure uniformity, it has become possible in many mills to determine in advance the proper settings and speeds of all machines which will result in the greatest output of each grade of goods, and the overseers can concentrate on getting this work out.

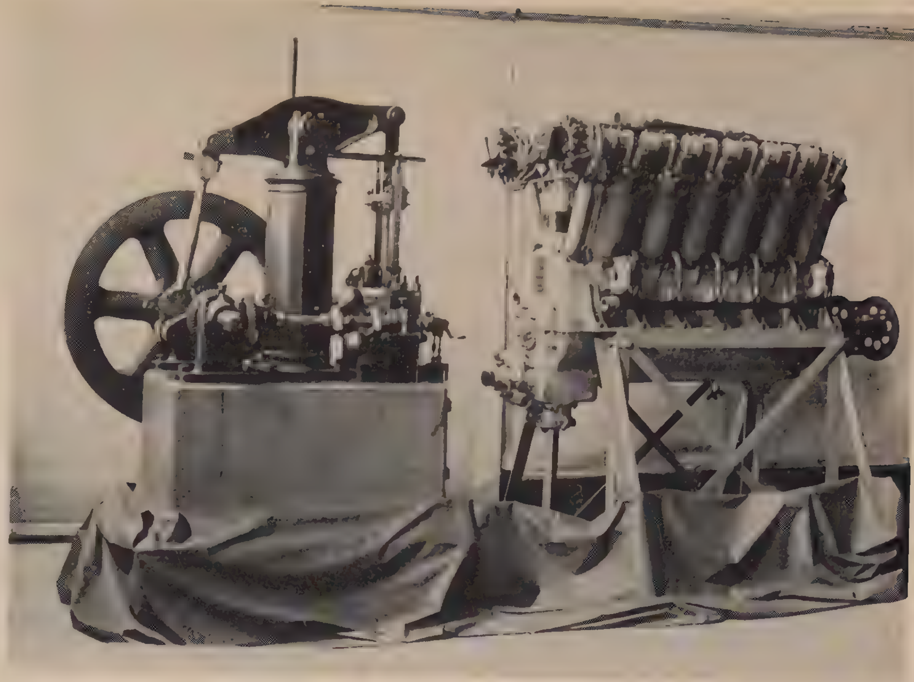
Both spinners and weavers spend much of their time looking for and tying broken threads, and, where studies to secure uniformity have greatly reduced this breakage, much more work can be done by each operative. Progress along this line has been so great in some cotton mills in states where the legal limit for women is forty-eight hours per week, that the disadvantage of short time is overcome by running the spinning frames and looms through the noon hour and possibly for some time after the operatives leave at night. These ma-

chines are all equipped with devices which stop them instantly if a thread breaks, so no damage is done to the work, and the workers do not object, as they are paid for what they produce and not for the time they are in attendance.

Many other present or promised improvements due to scientific investigation in the textile field could be mentioned. The studies into the uniformity of cotton yarns produced on a spinning frame show that they are stronger at some one position of the bobbin than at the others. This allows higher speed operation at this position, and a number of methods of taking advantage of this fact are being developed. The microscope is also coming into use in the study of fabrics and of cross-sections of threads imbedded in wax. The latter method is being applied at present to the investigation of different starch solutions used on warp threads before they go to the loom. Thus the oldest art known to man, long controlled by rule-of-thumb methods, is gradually finding scientific analysis and research of greater and greater use in its development.

B. *Mechanical Fabrics*

Mechanical fabric is the term applied to textile products for use where strength rather than appearance is one of the principal factors, as in rubber belts, automobile tires, balloons, airplane wings, and similar places. Because of this requirement machines for measuring the strength of these fabrics were used early in their development, and thus objective standards of accomplishment were established. This undoubtedly accounts for the rapid progress that has been made.



An old Brayton engine alongside of a Liberty airplane engine in the Brown University Engineering Laboratory.

One of the most interesting research developments along this line is found in the solution of the problem of getting a satisfactory covering for airplane wings. As lightness was equally important with strength, linen had been considered the only suitable fabric up to the time of our entry into the World War. Most of the flax came from Russia, however, and with the elimination of this source of supply, the British were not only unable to furnish the promised amounts for our airplane program, but even were finding difficulty in taking care of their own requirements.

The study of this problem was taken up by Mr. Ernest D. Walen, who was at that time in charge of the Textile Division of the United States Bureau of Standards. He began with an analysis of linen airplane fabric as a structural material, and decided that the desirable qualities were strength in relation to weight, elasticity, and ability to absorb the "dope," or filling, with which the cloth was impregnated. Experiments were then started in a number of mills under the general supervision of Mr. Walen to determine how the desirable characteristics of linen could be equalled or improved upon in cotton. After a considerable investigation of the cotton to be used and the methods of processing two fabrics were produced which were not only as good as linen, but were soon found to be superior to it for wing coverings. As a result all the fabric required for our extensive airplane program was supplied by American cotton mills, and large quantities were also furnished to our allies.

The continual progress in tire fabrics is of particular interest, as some of the earliest work in checking manufacturing processes against the strength of the finished

product was done in this line. Not many years ago, three thousand miles was considered a fair life for a tire, while now ten or twelve thousand miles is a common figure. On the other hand, Egyptian long staple cotton was used almost exclusively in the earlier fabrics and cords, and a combing operation was included in the process to eliminate all the short fibers, while today ordinary American cotton is used, and the combing process omitted. The many investigations into the strength of cotton yarns, the construction of the fabric or cord so as to receive the rubber, and the adhesion of the rubber, all measured by objective tests, are responsible for this development of the modern balanced tire, in which the thickness of the tread and the strength of the fabrics are both designed for the same operating life.

After receiving a number of complaints, a manufacturer of paper-makers' felts found on investigation that his product, which is one of the expensive parts of paper machinery, had a much longer working life in the plants of some customers than others. It was felt that the method of washing or cleaning these fabrics had a great deal to do with this difference, and this resulted in a study of the effect of all the different methods of washing on the strength of the product. This work, which was done at the Textile Laboratory of the Massachusetts Institute of Technology, brought out the interesting fact that some paper manufacturers were using such strong acids and soaps that the felts were ruined in a very few washings, while other methods resulted in comparatively little loss of strength. As a result the manufacturer who started this study was able to recommend to his customers methods of cleaning which elim-

inated needless waste and gave a longer life to his product.

The development of apparatus for measuring the strength of textile products has been of considerable use in investigations outside of mechanical fabrics. Sheet manufacturers have found that the same grade of cloth going to four different bleacheries came back four kinds of good as far as strength and elasticity were concerned. In the same way the finishing plants have been able to check their own processes. A laundry, having trouble with shirts made from mixed cotton and fiber silk, had some of the latter product tested and found that the strength was thirty-six pounds per square inch when dry, but only three pounds when wet. This indicated that the ordinary laundering processes could not be used on these goods. In these various ways the first step in scientific investigation, determining the facts in the case, is becoming of increasing service in the solution of textile problems.

C. *Standard Specifications*

A large part of the output of American cement mills is shipped in bags made from closely woven cotton cloth, and, because of their expense, the manufacturer desires to have these containers returned to him for further use. In a given case the bags from one lot averaged a half-dozen round trips before wearing out, while most of those in a second purchase were torn and full of holes when they returned for the first time. The cloth used in this lot was light and made from low grade cotton, but it had been filled with gum or clay along with starch in the finishing process, giving it temporarily the weight, "dust-proofness," and appearance of better

material. Because of such unscrupulous competition on the part of some cloth dealers and finishers, the cement manufacturers felt the need of suitable standard specifications for this fabric, but they did not know enough about textiles to draw them up. Such work, however, is regularly handled by the American Society for Testing Materials, so the textile division of this society recently appointed a subcommittee to take up this study.

Following the policy of the organization, this committee was made up of representatives of both cement mills and cotton cloth factories interested in this business, and men appointed from testing laboratories and public scientific bodies. Work is now in progress, the results of all investigations which bear on the problem being brought together, and new researches being stimulated among the members along special lines where additional information is desired. When this is complete, the committee will recommend standard specifications covering the strength, weight, threads per inch, and similar characteristics of the best types of fabric and giving the approved methods of testing or measuring these qualities. With this information at hand the problem will be greatly simplified for both the cement manufacturers and the honest cloth brokers.

A great deal along this line has already been done on other mechanical fabrics, and in these studies the method of testing strength became a problem of particular importance. The rate with which the load is applied or the fabric stretched has some effect on the breaking point, so a standard speed had to be adopted. A more serious problem arose from the fact that cotton absorbs moisture in a damp atmosphere and gives it up if the air is very dry. The change from a bone dry

condition to the maximum absorption of moisture in a very humid atmosphere results in about ten per cent increase in weight and in some cases a hundred per cent increase in strength, so the choice of standard conditions under which tests should be made, and the determination of the effect of variations from this condition required much research work.

While this illustration of the methods used in developing standard specifications was chosen in the textile field, it represents but a small percentage of the work of the American Society for Testing Materials. In fact, the standards of this society, developed through the research work of its members, are now generally specified for a large proportion of the materials used in both manufacturing and construction work in this country.

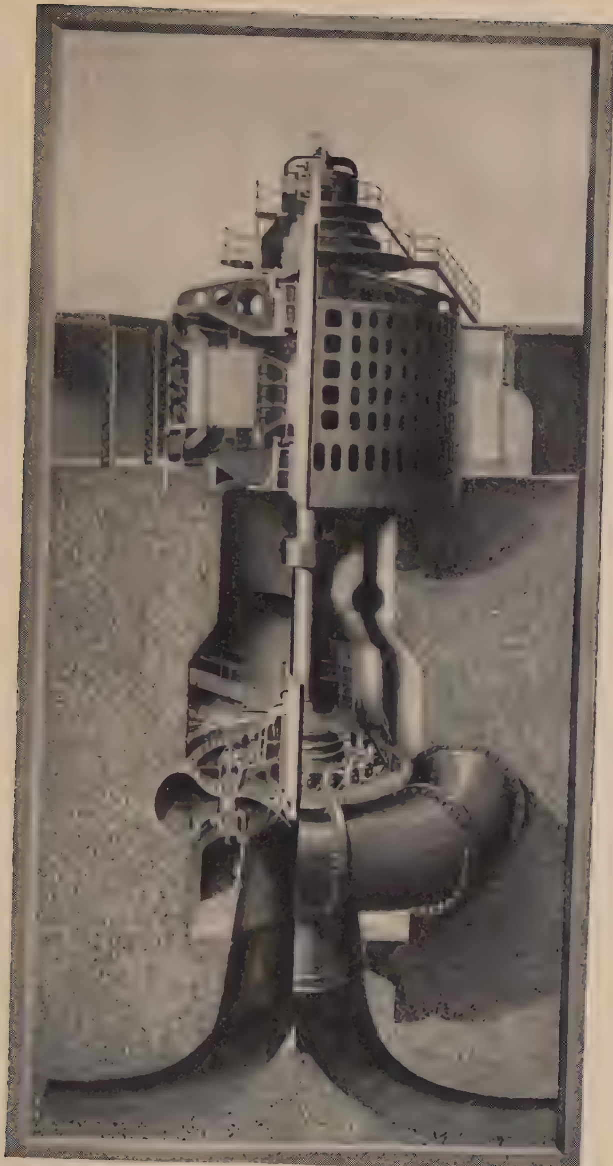
CONCLUSION

The origin and early development of most of the processes with which mechanical engineers now deal, occurred in a period when there was little connection between science and industry. The men who did this early work knew nothing of scientific methods, at least by training, and depended on their mechanical ingenuity and the building of experimental machines for improvements in the methods of manufacture. On the other hand, the scientist of that day knew little of the laws underlying many of these manufacturing processes, and took little interest in their improvement, so much credit is due to the inventive geniuses for the contributions they have made. In this respect mechanical engineering differs greatly from electrical engineering, where the early work was done largely by the physicists, and some-

times, as in alternating current power apparatus, the whole theory was developed mathematically before the first machine was built.

The mechanical engineer has done more toward putting his work on a scientific basis in the field of power generation than any other line, and it is significant that here the greatest advances in output and efficiency have occurred. However, progress along these lines was made much easier for the engineer because of the work done in discovering the laws and developing the theories of heat and of the flow of fluids by men in pure science. Most manufacturing processes, fire prevention problems, and such, in which the mechanical engineer is involved, are much more complex, and do not have such a background of scientific theory to draw on in guiding future development work. With the demand for progress so great that there is not time to await the inventions of a succession of mechanical geniuses even where their "cut and try" methods are satisfactory, the engineer has found it necessary to draw on such scientific laws and theories as bear on his problems, and then make use of scientific methods and apparatus in determining further facts so as to put such processes on a basis of exact and classified knowledge.

Some of the outstanding achievements in the production of power, the improvement of manufacturing processes, and the elimination of waste, which have already resulted from such scientific investigations, have been noted, and, with the increasing application of this type of research to the problems of industry, much greater progress may be expected. As a result of this activity, not only will the United States maintain its supremacy as a manufacturing nation, but the time will



Cross-section of largest hydraulic turbine in existence, showing particularly the draft tube arrangement.

soon come when it will be possible for every worker to produce sufficient wealth so that each may receive enough to assure and have sufficient leisure to enjoy a real American standard of living.

CHAPTER XI

SCIENTIFIC VS. CASUAL MANAGEMENT

DWIGHT T. FARNHAM

THE scientific method has long been known to men engaged in research but it is only within the last fifteen years that it has been consciously applied to industry under the name of Scientific Management. From the standpoint of production Frederick W. Taylor was the pioneer. Later similar methods were applied to marketing by certain of the advertising agencies. Only recently has this method been applied to finance.[1]

Before the scientific method was applied to industry there existed what might be termed casual management. Casual management was practiced by what was known as the "experienced business man" who depended largely upon "personality" and "shrewdness" to effect what he desired. Some of these men had analytical minds and applied the scientific method unconsciously. Such men were the outstanding successes. The balance depended upon meeting problems as they arose and settling them as best they could on a basis of what was known as "experience" or a "good hunch." If they were lucky and a majority of their guesses were correct, they prospered. Otherwise they joined the 95 per cent of business failures.

[1] See Analytical Credits by Alexander Wall, Financial and Operating Credits by Bliss, and books on Finance by Arthur S. Dewing and Lough.

The successful men of the second class were very often successful through fortunate combinations of circumstance. They started a business in a section of the country just on the verge of a boom, or they entered a business just on the verge of a great popular demand, or they possessed a super personality or were born to valuable connections.

Great possessions do not necessarily imply great ability. Acquisitive power does not necessarily imply executive ability. Nor does the fact that a man is a "good trader" or possesses personal charm prove that he is a good administrator. Consequently possession of a majority of the stock of a corporation for a time by an individual associated directly with the management has in the past been no guarantee that an industry is efficiently operated.

To make the situation worse, it is very difficult for a man to pile up a million dollars without reaching the conclusion that he possesses vast ability of every sort regardless of whether his acquisition of this sum is due to fortunate circumstances or to wise administration. As a result, very great opposition to new ideas often exists on the part of such self-made captains of industry. Inasmuch as they have made a million they don't propose to learn from anyone who has piled up less. The self-confidence that was an asset during the struggle to acquire a million very often becomes a liability in the form of an enlarged ego once the million is secured. As a result unbelievable inefficiency is often present in organizations controlled by such individuals.

The earmarks of such an organization are usually somewhat as follows:—

a. The boss "hires the kind of men he likes"—which

means men and women who continually flatter him and never oppose him. This means a low grade of executive personnel.

b. These sycophants—since they know that pull is the really important thing—conceal the true state of affairs from the boss, even if they know operating conditions are rotten. They work on the principle that "what the boss doesn't know won't hurt *them.*" They are experts principally in reading the boss's moods and applying the most pleasing treatment.

c. Every decision, no matter how trivial, is referred to the boss. The way to avoid blame for making mistakes is never to do anything without orders. Consequently the boss is always deciding things intuitively, under pressure, without the facts in the case.

d. The whole organization is one mass of intrigue whose ethics are somewhat on a par with those of the more decadent French courts. Each executive spends about two-thirds of his time in industrial politics and the other third running his job—after a fashion.

e. Since everyone is expected to know his job, no one dares say "I don't know" to the boss. The result is improvisation and costly lies instead of research.

f. Since only about so much sweetness exists in ordinary human nature each executive recovers from the abnormal drain of flattering the boss by abusing his subordinates. The executives all agree on methods of dealing drastically with any subordinate who so far presumes as to go over his superior's head. As a result the organization is full of bullies and of petty persecutions. The result is a low grade rank and file.

g. Workmen are fired on the whim of their foremen. Consequently the type of workman who remains with the

organization is the one whose desire to loaf is greater than his desire to retain his self-respect. On the whole the labor turnover is usually enormous.

h. Workmen are for the most part paid by the day, as it is easier for the uneducated foremen and timekeepers to stalk around through the plant and see that a man is there and that he *appears* busy than it is to establish standard tasks and then see that he performs them satisfactorily. Such piece rates as exist are usually set by guess and bargain and systematic soldiering is rife. Quality inspection is often under the superintendent responsible for the quantity produced.

i. Foremen root around for their own supplies and when they get their hands on something they feel they may need later they hide it. (In one plant we found \$200,000 worth of tool steel which did not appear on the inventory. In another they were using a \$50,000 chunk of platinum as a paper weight.) Workmen take home anything that might be useful. (In one case three workmen got away with a disassembled sewing machine in spite of watchers at the gate.) When a foreman can't find something he wants in his own department or in what passes for a storeroom, he orders some more from the purchasing department. Inventories are taken annually—by physical count. The men sharpen their own tools.

j. Planning within the department is done in the foreman's head. Interdepartmental planning is done by foremen visiting around from department to department. Under the circumstances the chance of all the needed parts of a product being on hand when the product is assembled is fairly remote. (A ninety-ton propeller shaft was "lost" on the night shift in one of our best known

plants. It was found under the floor five years later where the crew who had spoiled it had hid it to avoid censure.)

k. Production costs are inaccurate with overheads distributed by some rule of thumb method which makes it possible to sell goods below cost at prices which seem to show profits and to lose business bid on at supposed cost.

l. Accounting and costing are in charge of some weak-kneed and ineffective bookkeeper, the height of whose ambition is to "balance everything to the cent." There is no comptroller in the real sense of the word and no statistical department. The treasurer is some superannuated stockholder whose duties are limited to reading his annual report. Statements and costs are late and misleading.

m. Organized research doesn't exist. There is a little experimental work done by the crank inventor type of foreman or workman. The boss may have a brilliant idea now and then, but improvement of the product and the development of new products are left to chance. Anyone who really has anything keeps it secret and patents it himself, knowing from bitter experience that there are a lot of people prowling around to pick up something with which to curry favor with the boss and that neither credit nor reward will be theirs if one of these hyenas gets wind of a good idea.

n. Rejections by the customer are usually decided to be the fault of the customer or of the transportation company. The company is usually engaged in a number of law suits.

o. The sales manager believes in "bare-handed salesmanship" which consists in a mixture of cunning flattery

and hypnotism applied to the prospect in personal visits. He bombards his men with "peppy" sales bulletins purchased from an agency and is always writing them letters hauling them over the coals for not selling more goods regardless of circumstances. He doesn't know what a market survey or a sales school is and he doesn't believe in sales statistics. His men all hate him and lie to him for the short time they remain with the company, and the whole sales department hates the factory organization. The firm's advertising is placed with a good mixer who spends a lot of money entertaining the boss.

p. Credits are handled by some clerk whose bible is one of the regular services and whose knowledge of credits is limited to "looking it up in the book."

q. The boss aided and abetted by his old-fashioned banker believes in "keeping down overhead" by paying small salaries to cheap men. As a result his whole organization is overmanned, overequipped and undersupervised.

It would be possible to go on almost indefinitely with this sort of thing. There is not the least exaggeration in the conditions we have cited. The examples represent the state of affairs in the usual moderate sized business a few years ago—and a state of affairs which still exists in far too many concerns. There has been, however, a decided general improvement in management methods during the last dozen years,—due to the war, to the growth of reliable literature on the subject, and to courses in business administration and industrial engineering at our leading universities. Production management has been pretty well covered according to the scientific method. There is still much work to be done in the field of sales and finance.

As a matter of contrast we propose to outline roughly conditions in a business conducted according to the scientific methods which have stood the test and have been accepted by our most enlightened business men:—

The man at the head of the modern effectively conducted business probably has quite as much personality and force as the boss we just described but he possesses more character. His self-confidence is based on years of self-knowledge and the earned confidence of his associates. He knows the subtle poison of flattery and his subordinates aren't encouraged to waste company time feeding his personal vanity. He has learned to delegate authority and his organization knows that each man is judged by his honest effort as well as by his results. No one is afraid to tell him the truth as his organization knows that the only unforgivable sin is suppression of facts.

He is respected but not necessarily "popular." He always has time to sift an apparent injustice to the bottom and he is absolutely fair. He knows a great deal about human nature and does not expect perfection. His criticism is constructive and he is not afraid to praise. He is always ready to assist in the solution of a problem—either personally or by securing the required information from an expert. He provides his organization with proper equipment and does not expect them to answer his questions without reflection and research. He is unhurried and courteous. He has time for constructive thought. He asks rather than orders.

Needless to say his organization is loyal and the turnover is low. Industrial politics are at the minimum and it is safer to earn recognition by hard work than to in-

trigue for it. Bluffers and flatterers go elsewhere. The organization is composed of able men and women capable of standing on their merits, always studying to improve themselves and to deserve advancement. The whole organization operates like a high grade machine—quietly, rapidly and effectively.

Careful distinction is made between the administrative and executive functions and between staff and line. There is a well organized statistical department and research work is well organized and equipped.

The comptroller is responsible for all the financial information required for intelligent decision reaching the management regularly and promptly. Under the head of administrative control, charts would be prepared covering somewhat the following ground:

I. FINANCIAL

1. Financial forecast—contrasting probable receipts and expenditures as shown by the budget and showing bond interest, dividend payments, etc.

2. Balance sheet ratios for a period of ten years past:

a. Current assets to current liabilities—indicating degree of liquidity. Should average 200-300 per cent.[2]

b. Receivables to inventory—indicating reasons for fluctuations in "*a*", inventory policy, etc.

c. Reserves to total assets—indicating degree of conservatism. Should be at least 3 per cent.

d. Cash to current liabilities—indicating cash position. Should be at least 25 per cent.

e. Fixed assets to net worth—indicating appor-

[2] These figures vary for every business so that those given must be taken merely as an indication of the desirable limits in average sorts of business. See books by Wall & Bliss, previously cited.

tionment of stockholders' interest. Should be below 60 per cent.

f. Receivables to sales—indicating collection policy. Should be below 30 per cent.

g. Inventory to sales—indicating size of inventory. Should be below 40 per cent.

h. Sales to net worth—indicating activity of stockholders' investment. Should be at least 200 per cent.

i. Debt to net worth—indicating relation of creditors' to stockholders' interest. Should be below 60 per cent.

j. Sales to fixed assets—indicating vitality of fixed assets. Should be at least 300 per cent.

k. Profit to net worth. Should be at least 8 per cent.

3. In addition the following figures and turnovers should be charted:

a. Net working capital (current assets less current liabilities).

b. Book value common stock (capital stock and surplus divided by number of shares common stock outstanding).

c. Percentage of earnings left in the business.

d. Turnover of all capital—(net sales divided by total capital employed).

e. Turnover on fixed property (net sales divided by fixed assets).

f. Turnover of inventories (net sales divided by inventory).

g. Turnover of accounts receivable (net sales divided by accounts receivable).

h. Volume of sales in units shipped per dollar

of plant investment (volume of sales in lbs., etc., divided by fixed assets).

i. Operating profits on total capital (operating profit divided by total capital employed).

j. Sources of earnings (net or gross earnings apportioned to physical assets and departments in per cent of investment in each).

k. Sources of capital (divide each liability item on balance sheet by total capital employed).

l. Cost of borrowed money (interest costs divided by sum of notes payable and long term liabilities).

m. Fixed property expense percentage on plant investment (expenses making up cost of sales and cost of doing business divided by fixed assets).

n. Analysis of accounts and notes receivable according to age—over 30 days, 90 days, 6 months, 9 months, one year, etc.

o. Analysis of inventories—raw materials work in process, finished stock, supplies. Show quantity of principal items.

p. Analysis of fixed assets.

q. Average prices or price index.

r. Analysis of cost and expense in per cent of sales as follows:

1. Net sales in dollars.
2. Manufacturing costs:
    - *a.* Material.
    - *b.* Labor.
    - *c.* Supplies.
    - *d.* Factory expense.

      Total
3. Overhead costs.
    - *a.* Sales expense.

b. Administrative expense.
c. General expense.
Total

4. Operating profit.
5. Interest costs.
6. Surplus net profits.
Grand total (to check *l*).

s. Annual loss from bad debts in per cent of sales.

t. Market range in common stock.

u. General barometrics—as given by the Harvard, Babson and similar services—car loadings, bank clearings, interest rates, failures, commodity quotations, etc.

II. SALES

1. Total sales in dollars.
2. Sales by products—dollars and quantities.
3. Seasonal sales—dollars by months, each month in per cent of total sales per year.
4. Sales vs. shipments vs. orders received by months.
5. Analysis general sales expense.
6. Sales in dollars by territories.
7. Earnings by branches.
8. Analysis territorial sales expense by branches.
9. Tabulate and chart—

a. Territories by name.
b. Market by territories.
c. Quotas by territories.
d. Percentage quotas are of markets.
e. Percentage of quota shipped to date on basis of quota to date.
f. Average quantity required annually per customer in each territory.

10. Competitive analysis.

a. Tabulate principal competitors in order of size and sale (as far as can be estimated).

b. Prices and costs—self vs. competitors (estimated, of course).

c. Quantity of advertising—self vs. competitors.

d. Quality own vs. competitors, product (use army rating plan covering depreciation, appearance, service, etc.)

e. Competitors, sales force—territorially by numbers.

III. PRODUCTION

1. Plant output vs. sales—quantities.
2. Total and departmental outputs—quantities.
3. Unabsorbed burden—total and by departments—to show loss due to less than standard production.
4. Departmental losses.

   a. Spoiled material in dollars and in per cent of output.

   b. Idle time in dollars and per cent of total time.
5. Departmental and total plant efficiency in per cent of standards attained.
6. Labor turnover—total and by departments.
7. Labor control—

   a. Surplus of quits over hired.

   b. Wages in district.

   c. Welfare analysis.
8. Departmental working force.

It is of course obviously impossible to do more than indicate the sort of facts required for intelligent administrative control. Every business differs and a set of charts which would not be sufficient for one business would be extravagance for another. We have given the financial

charts in greater detail than the others because there is less variation in the financial element in different businesses than in the sales or production. It is of course assumed that the administrator will have the usual accounting and cost statements properly prepared on the dates due.

Naturally each administrator must, together with his comptroller, work out a list of the charts which can be prepared without undue expense but which will give him, in true perspective, exactly the information he should have brought to his attention each day, each week, each month, each quarter, and each year.

Study of the titles we have listed will make clear the necessity for supporting information which space has not permitted us to list. For instance, the financial forecast (I-1) calls for sales quotas and a budget. Sales quotas for salesmen's reports on prospective business. The estimate of the market for the product under II-9-*b* calls for market analysis and market tests.

Analysis of the manufacturer's own and of his competitors, product (II-10) calls for research of a cost careful and accurate sort. Most sales executives begin to give you "talking points" when you ask for this sort of thing. Talking points are the last thing wanted. The idea of the competitive analysis is to find out which product is best, just how much the best it is, and why it is the best. This means research and in nine cases out of ten leads to further research. In one company we found the salesmen had no idea whatsoever of the intrinsic merits of the product they were selling as against that of competitors. In the investigation which followed it was discovered that a number of old foremen had bought competing products at their own expense and had analyzed them for

their own information. Here was a great mass of information simply waiting to be organized and used. In another plant it was found that a $350 device which had been added to a machine as a "talking point" was not only of no earthly use but was an actual detriment to the machines' operation.

Such analyses have even shown that a company really had no *raison d'être*—that it had nothing to sell. This discovery in more than one case that has come to my attention has resulted in research under forced draft until something was found and perfected that furnished the business a real excuse for existing.

The wise administrator, however, does not wait for his ship to sink under him. He has charts, a lookout and the best technical instruments and he is busy always hunting a better way or a better result. Success today means knowledge and skill—and the knowledge must come first or the skill is likely to be misdirected. Executive power without administrative control is a Rolls-Royce with a drunken man at the wheel.

Charts showing departmental losses of material (III-4-*a*) naturally serve as alarm clocks to start the wheels of investigation. This means investigation of the quality of raw materials and of their behavior in process of manufacture, in shipment, and in use—all research work for the staff.

Charts showing loss of machine time and man-hours (III-4-*b*) require investigation of production by the industrial engineering staff. If the plant possess a modern production control department which insures the right thing in the right place at the right time or records the reason for failure, this is easy. If it does not, the management will not be aware that such losses exist. The

president will only know that his competitors continue to undersell him and still make a profit.

In the properly standardized and organized plant the actual efficiency in a percentage of standard performance in each department may usually be known at least once a week (III-5). This implies standardized routing, standardized tools, standardized equipment, standardized materials and standardized operating times. It implies that workmen are paid on a basis of work performed instead of on time served. It implies that they are paid in proportion to accomplishment in both quality and quantity and that all standards have been set scientifically with a stop watch. It usually implies that foremen, superintendents and sometimes even managers are paid bonuses based upon the efficiency of their departments. In the properly organized plant it is to the interest of all concerned to operate the plant as a whole with the maximum degree of effectiveness which existing conditions permit.

The facts in regard to labor turnover (III-6) are of vital importance. These should be worked out for the plant as a whole and for each department each month and charted for a period of at least three years. The cost of breaking in new employees has geen generally conceded to vary from $20 to $200 per employee, depending upon the intricacy of the work and the fragility of the product throughout industry. It is almost impossible to remedy a difficulty whose existence or whose extent is unknown. Study of seasonal and cyclic fluctuations in labor turnover together with departmental turnovers furnish a knowledge of facts and tendencies which lead to types of research which obviate unnecessary expense for breaking in new workers.

Labor control (III-7) periodically furnishes the facts which govern the setting of base wage rates. In order to carry maximum net profits, a business must pay its employees the least amount in wages and welfare work which will secure loyalty and satisfaction sufficient to result in continuous quality and quantity production.

Workmen go where they can make the most money in the pleasantest way. Certain types of industry attract certain classes of people. There are enough people in every community who desire the dignity, surroundings and hours of labor existing in bank work to keep bank clerks' wages close to the starvation point. The type who applies for the job as negro porter is obviously not competing with bank clerks nor with bricklayers for jobs.

It therefore becomes necessary in each community to determine by analysis the industries competing with a given concern. Once done it is easy to secure from applicants for jobs or from other sources the wages competing industries are paying. These should be averaged and charted in comparison with those paid in the concern in question (III-7-*b*).

Similarly welfare activities are analyzed in industries competing in the local labor market and charted (III-7-*c*) in the order of their determined value to the worker. In one city such a welfare analysis disclosed the fact that employees in a certain plant obtained benefits from a company store worth nearly a dollar a day in wages.

Another chart (III-7-*a*)—which in times of stress should be prepared weekly—shows the surplus of quits over hired. When no special policy of increasing or decreasing the working force is in effect the change from surplus to deficit of quits over hired indicates a flow of

labor away from the plant. This becomes an immediate alarm bell which calls for further investigation into the length of service of the quits. If the plant is losing the "employed one week or less" class, the matter is not serious. If the "90 day class" is leaving the necessity for immediate action is indicated. The Wage Rate Committee, consisting usually of the plant superintendent, industrial engineer and personnel manager, then automatically goes into session, examines the facts as shown by charts "b" and "c" and by detailed discussion with the personnel manager, and recommends action to the management.

By the use of this device it is possible for a company to pay just as high base rates as are necessary—and no higher—to keep its experienced men from leaving and becoming dissatisfied. The decision is based upon facts which can be shown a board of directors and not upon "hunch," rumor, or upon something equally intangible and uncertain, and the company can be sure of "paying its employees the least amount in wages and welfare work which will secure loyalty and satisfaction sufficient to result in continuous quality and quantity production."

The departmental working force chart (III-8) is kept up weekly or daily. In some cases—especially in the continuous production type of industry—the standard number of men required to "man the ship" are carried against the actual. This is a rough and ready type of index which, especially if combined with the weekly payroll and output, gives the management an idea of efficiency and expenditure some time before the more carefully prepared figures are ready.

So much for the facts which enable the manager, who predicates his policies upon the application of the scien-

tific method to industry through administrative control, to operate his business as effectively as controllable conditions allow. These facts necessarily differ in every business but once those necessary to intelligent financial, sales, and production management are determined, it is comparatively inexpensive to keep the charts up to date and to base decisions as to policy upon them.

Under scientific management the duties and responsibilities of each line and staff executive are defined in writing and the relation of each to the whole are shown graphically upon an organization chart.

Such a chart, in order to be effective, must be drawn up by someone conversant with the best extant types of organization in various modern industries and with a wide experience with human nature, after a careful study of the existing organization and of those who compose it.[3] It should deal with the duties of the entire organization along somewhat the general lines covered by the following paragraphs which are excerpts with the detail omitted from the description of an organization chart in actual use in a certain industry:

"*Stockholders*—having invested money in the business are entitled to safety of their invested principal and to interest, in the form of dividends, upon their investment. To attain this end they appoint annually a—

"*Board of Directors*—whose duty it is to see that the affairs of the company are so conducted that the capital invested by the stockholders is safe and that maximum dividends consistent with such safety are earned and paid regularly to the stockholders. To secure effective operation they keep in touch with the conduct of the

[3] See also "A Practical Operating Organization," *Administration*, April, 1923.

business, authorize the management to perform certain acts and appoint an executive committee and various officers to carry on the business of the company.

"*The Management*—consists of the officers appointed by the board to conduct the business of the company. It is the duty of the management to so handle the affairs of the company that the maximum earnings consistent with the safety of the stockholders' investment are secured continuously. This means that goods manufactured as cheaply as possible must be sold at a minimum expense for the highest prices obtainable consistent with obtaining the maximum volume of sales. This implies fair treatment of every member of the organization, of customers and of the public in general. The management must be organized to operate continuously and to that end it delegates certain duties to others.

"*The Advisory Board*—consists of the sales manager, works manager and treasurer with the general manager acting as chairman. This board should meet regularly at a stated time to discuss questions of policy and routine operating matters concerning all departments. Available facts in regard to matters to be discussed should be secured beforehand. Meetings should be brief and should follow a regular order of business.

"The management is also advised by staff counsel—legal — accounting — financial — engineering — research —advertising and the like, who—with the Advisory board—act as staff to the management in the study and solution of various operating problems.

"*The Sales Manager*—whose duty it is to secure the sale of the largest possible volume of goods at the highest price circumstances permit at the least cost to sell. It is also the duty of the sales manager to dispose of all

German method of storing material.

goods manufactured which are of sufficiently good quality to serve the purpose for which they were designed, provided they will do this for a sufficient length of time to maintain continuously the reputation of the company.

"He is in charge of all salesmen and of all branches of all companies and is responsible for the conduct of each.

"*The Treasurer*—is responsible for the provision of sufficient working capital at all times and for the funds of the company being so handled that they will earn the maximum which existing conditions permit. As *Comptroller* he is responsible for the preparation at a minimum expense and for the presentation to the management of the facts necessary to intelligent conduct of the business. To that end he is in charge of the accounting cost and statistical departments and of the office force. In connection with the treasurer's responsibility for the handling of funds he is in charge of the *Purchasing Department,* which is responsible for buying at the lowest price consistent with quality sufficient materials and supplies to permit continuous plant operation.

"*The Works Manager*—is responsible for the production of the largest possible quantity of goods of saleable quality at the lowest cost for labor, material, supplies and overhead. In this work he is assisted by—

"*The Plant Superintendent*—who is responsible for maintaining expenditures for labor at the minimum consistent with maintaining the quality and quantity of the product and for the elimination of wastes of labor, material and supplies. In this he is assisted by:—

"*The Production Control Department*—which is responsible for the elimination of waste of time and for the shipment of the product as nearly upon the date promised as circumstances permit. This implies responsibility

for the presence of the right thing, in the right condition, in the right place at the right time throughout the process of manufacture.

"*The Stores Department*—which is responsible for the elimination of wastes of materials and supplies and the delivery of required materials and supplies in proper condition when and where wanted.

"*The Plant Foremen*—who are each responsible to the superintendent for the efficient operation of their respective departments.

"*The Engineering Department*—is responsible to the works manager for the preparation of all designs drawing and shop orders for use in the shop in such a manner that expense of manufacture and misunderstandings with customers may be reduced to a minimum.

"*The Estimating Department*—is responsible to the works manager for careful estimates of cost on all new work, etc., etc., etc."

Such a chart gives each member of the organization a clear idea of his responsibilities and of his relations to the business as a whole. It reduces industrial politics if properly enforced by the management. The detailed description of duties serves as standard practice instructions to the existing force, thus preventing misunderstandings and simplifying the instruction of novices.

More and more business men are realizing that there are four types of earnings in business—the profits which accrue from—

1. The wise purchase of materials.
2. The efficient management of the plant.
3. The effective operation of the sales department.
4. Careful finance.

The relative importance of each varies with the type

of business but in nearly every case each of the four basic departments contribute to the success or failure of the company. In one case profits of $80,000 were wiped out by an unfortunate purchase of a large quantity of sugar just before the bottom dropped out of the market in 1920. A very large industrial consolidation was a failure because its promoters did not realize that each constituent concern depended for its earnings upon speculative buying and not upon efficient manufacture. A purchasing agent is often in a position to make or break a company.

About fifteen years ago as superintendent of a manufacturing plant, I found that my production costs varied to a greater extent with the cost of materials than with efficient operation. I got tired of being blamed by the general manager for rises in costs caused by factors beyond my control and induced the management to set up arbitrary raw material costs, turning over to the plants producing the raw materials—which were also controlled by the same company—the difference between these arbitraries and their cost of production. The superintendents of the raw material plants were glad to be able to show an increased profit when they made special efforts to reduce costs and my manufacturing costs also reflected the efficiency with which we operated the factory.

Purchase profits can be determined in this way but a better way is to figure up raw materials at both cost and market price. The difference represents the profit and loss of purchase.

The determination of manufacturing and sales profits requires the establishment of standards or arbitraries of some sort. Financial profits are easily determined.

Once each of the four departments is placed on a profit and loss basis, the executive in charge of each is on his mettle because he knows that he has a definite part in the production of total net earnings and will be judged in accordance with results. The wise general manager sets each of his department heads up in business for himself in so far as circumstances will permit and pays each in proportion to what he accomplishes.

Casual management is management based upon guess, "hunch" and "experience." Under it are rife all the weaknesses of human nature. Scientific management is management based upon facts with administrative policy determined by statistics and research and with executives and their subordinates motivated by fair treatment, by accurately placed responsibility, and by reward in proportion to accomplishment. Consciously or unconsciously our leading industries are applying the scientific method more and more to production, to sales and to financial management. The proof is the vast literature on the subject and the rapid increase in courses in management in our schools and universities.

CHAPTER XII

RESULTS OF SCIENTIFIC MANAGEMENT

Dwight T. Farnham

One of the principal reasons why scientific management has not been duly credited with the economies it has effected has been because it has, in the majority of cases, been applied by engineers who have been more interested to do the creative work than to stop from time to time and figure out in dollars and cents just what the work had cost, how much it had saved and how profitable it had proved.

One firm of industrial engineers took in a million dollars in fees. They estimated that they had saved their clients at least ten million dollars but they had no figures to prove it either in whole or in part. Another firm took in more than a million and a half dollars and were unable at the end of that time to present a single final report showing dollars and cents savings. Both these firms had plenty of letters from clients stating that the work had saved the fees paid many times over. Unfortunately the usual industrial engineer has not been commercially minded.

There have been exceptions of course. A large steel company in Chicago which had some thirty people in its industrial engineering department never undertook a new piece of work without preparing an estimate of the prob-

able cost of the work and of the probable savings, on a form provided for this purpose. When the work was finished the accounting department entered the actual cost and saving in the place provided and the work was declared profitable or a loss. Needless to say, the department managed so to select and handle work that the results shown by these sheets were seldom in the red.

My own first attempt to apply scientific management—although I did not then know it by that name—to a plant, occurred in 1906. I was superintendent of a factory on the Pacific Coast which after a year under a drunken superintendent had just been through an interregnum under a foreman. The plant was in a chaotic condition from morale to machinery and in sheer self-defense it became necessary to organize the routing operation of the different departments separately from the staff investigation.[1] I took over the staff work as superintendent and turned the routine over to an assistant superintendent. As a result in about a year and a half we cut costs 30 per cent, increased output 50 per cent and quality 20 per cent.

The same principles and methods subsequently applied to another plant in less than a year resulted in a substantial reduction in manufacturing costs, an increase in production of nearly 30 per cent and an increase in quality of 13 per cent.

In another and much larger plant labor costs—not wages—were cut 15 per cent, output was increased over 50 per cent, quality was increased 38 per cent. Labor costs were reduced as much as 50 per cent in some individual departments. Repair costs were reduced 33 per

[1] For details see "Scientific Management for the Factory of Moderate Size" in the Engineering Magazine, October 1915.

Modern type of factory building used by one of Germany's great vertical trusts.

cent. Oil costs were reduced $1500 a year. Meantime the morale and loyalty of the workmen in all three plants was so improved that when the I. W. W.'s attempted to organize the plants a year or so later, the workmen themselves organized a defensive league whose purpose was to chase organizers away from the plant.

Characteristic examples of actual savings effected by the introduction of scientific management follow:—

Pig iron handling: Unloading from box cars—wages increased from $.16 to $.27 per hour; output increased from 2 tons to 10 tons per hour; costs cut from $.27 to $.08 per ton. In Bethlehem Steel Co.'s yards, various movements—wages increased from $1.15 to $1.85 per day; output from 12 tons to 48 tons per day; cost cut from $.097 to $.038 per ton.

Shoveling: Various materials in Bethlehem Steel Co.'s yards—wages increased 63 per cent ($1.15 to $1.88 per day); cost per ton reduced 54 per cent (from $.073 to $.033). The saving the first year amounted to $36,000 the second year to $80,000.

Iron molding—wages increased 75 per cent ($3.28 to $5.74 per man); output increased 265 per cent (time cut from 53 to 20 minutes per piece); and costs cut 53 per cent ($1.17 to $.54 per piece).

Bricklaying: Union men averaged 350 brick per hour instead of 120, with less fatigue, making five motions instead of 18.

Riveting: Crew drove 731 rivets per day on structural work instead of 432 per day—an increase of 69 per cent.

Cleaning boilers: Cost cut from $62 to $11 per set and work done more easily and more thoroughly.

Sulphate pump mills: Output doubled, cost reduced.

Tobacco pouch factory: Girls averaged 550 per day instead of 275, an increase of 100 per cent.

Bicycle ball factory: Wages increased 90 per cent, hours shortened from 10½ to 8½, quality improved, cost reduced.

Pillow case factory: Wages increased 40 per cent; production increased 33 per cent; cost cut in half; imperfections per case cut from 47 to 2.

Cloth mill: Wages increased 40 per cent; production increased 80 per cent; cost reduced 60 per cent; quality improved.

Foundry: Wages increased over 60 per cent and cost cut 66 per cent on big cylinder bushings.

Machine shop: Wages increased 17 per cent; output increased 41 per cent; cost reduced 60 per cent.

Foundry and machine shop: Wages increased 69.2 per cent; working day cut from ten to nine hours; and a saving of $120,000 per year effected.

The establishment of standards through staff investigation in certain shops whereby the equipment best suited for the work has been determined has accomplished remarkable results, for example:

a. Standardized belting has increased the average life of belts sixfold, the belt failures are one-sixth and the annual cost is less than one-seventh what it was.

b. High speed steel in machine shops accomplishes from four to five times as much as ordinary steel.

c. Standardized abrasive wheels cut four times as fast as old-fashioned ground stones.

d. Standardized files last four times as long and cut much faster.

In a locomotive shop rearranging the machines doubled the output and reduced labor costs.

Railroad fuel per 1000 tons of train weight per mile was reduced from 260 to 80 lbs.

Laborers excavating in one case were found to be 28 per cent efficient and rough labor in a steel yard 28 per cent efficient. Both were subsequently raised to 100 per cent.

In a railroad shop the expense of maintaining shop machinery was reduced as follows:—

1904 Expense	1907 Expense	1904 per Unit	1907 per Unit
$487,171.00	$315,844.00	$10.31	$4.89

In the same shop belting breakdowns were reduced from 12 per day to 2 per day. In the paint shop the provision of a separate brush for each color enabled two men and two helpers to do twice as much work of better quality than had previously been done by six men.

In a machine shop maintenance charges were reduced 68 per cent, being equivalent to a saving of $503,935 per year on a unit of output basis.

In a machine shop, boiler, erecting shop, blacksmith shop and foundry it was estimated by the engineers that output could be increased 60 per cent in six months without adding to working force equipment or payroll more than 10 per cent. Less than a year later the general manager reported an increase of 69.2 per cent in output with a payroll $120,000 a year less with a 9-hour instead of a 10-hour day.

In another plant results were as follows:—

Date	No. Men	Tons per Man	Total Tons	Pay-roll	Payroll per Ton	Increased Pay per Man
September 1908 ..	527	4.69	2,473	$29,380	11.88	0
July 1909 ..	263	9.04	2,377	15,248	6.41	2.0%
August 1909 ..	298	10.51	3,133	17,280	5.51	10.0%
September 1909 ..	312	10.92	3,408	17,394	5.14	17.3%

The following are typical instances of what has been accomplished:

In one plant where the engineers undertook work, the normal average standard for common labor, handling bars from rack to truck, weighing and checking orders, was determined to be 42,000 lbs. The results accomplished by two workmen under guidance is shown below:

WORKMAN NO. 1

Actual	March 1 Standard	Per cent Eff.	Actual	June 1 Standard	Per cent Eff.
25,000	42,000	60	44,000	42,000	106

WORKMAN NO. 2

Actual	March 1 Standard	Per cent Eff.	Actual	June 1 Standard	Per cent Eff.
31,500	42,000	73	56,700	42,000	135

FOUNDRY RESULTS JANUARY 1 TO AUGUST 31

	Jan. 1-Apr. 30, 4 Months	May 1-Aug. 31, 4 Months	Increase	Decrease	Per cent
Gross castings—tons	2290.61	2007.27			
Good castings "	1999.44	1733.22			
Pounds per molder per day					
Gross castings	1317	1970	653		49.6
Good "	1150	1701	551		47.9
Average per ton cost (Metal not included)					
Gross castings	$25.19	$22.03		$3.16	
Good "	28.86	25.30		3.56	12.3
Production by months					
Good castings—tons	409.92 Jan.	532.66 May			
	535.40 Feb.	478.26 June			
	562.55 Mar.	291.68 July			
	491.40 Apr.	430.62 Aug.			

For the first five months from January 1 to May 31 a plentiful supply of work was available for the working force—but during the months of June, July and August the supply was at a low ebb, necessitating the laying off

of good workmen and militating against a much larger probable improvement in individual productions.

Engineering work was begun May 1.

The consulting engineers undertook this contract (steel foundry) on an estimate to effect a reduction of \$4 a ton in 24 months. Work was begun in September and finished in the following May.

Months	Av. No. Men	Av. Tons per Man	Tonnage	Payroll	Payroll Cost per Ton
September	527	4.69	2473.1	\$34,976	14.14
April	176	12.07	2125.8	10,300	4.41
Results	351	7.38	347.3	\$24,676	9.73

	July	November	Gain	Per cent Gain
Pounds good castings per hour	12,917	16,061	3,134	24.3

			Saving	Per cent Saving
Payroll per hour	\$22.74	\$21.05	\$1.69	7.4
Labor cost per 100 lbs......	\$ 0.176	\$ 0.134	\$0.042	23.9

Production gain per month	376 tons
Labor savings " "	\$1,617.60

What was accomplished in a boiler shop for a plant desiring cost reduction is shown below. Not only were costs reduced to a tremendous extent, but production per man was at the same time increased over 250 per cent.

No. of Men on Payroll	Payroll	Monthly Tonnage	Tons per Man per Month
Before Service			
543	\$34,000	2,600	4.75
After 10 Months' Service			
180	10,000	2,200	12.

The following tabulation shows the results of work in connection with riveting gangs on structural work:

Before Installing the Methods

No. of Gangs	Av. No. Rivets per Gang per 10-hr. Day	Cost per 100 Rivets	Monthly Tonnage Output
12	400	$1.60	2000
After 9 Months' Service			
5	1650	.75	2000

In a foundry making small intricate castings the production of good castings per day was doubled within five months' time, with the total cost per 100 pounds remaining constant.

Statement of payroll and output of a small shop, first six months, first year, compared to first six months, second year, follows: (Standardizing work was begun June 1).

	1st Year	2d Year
Payroll	$167,780.04	$136,135.33
Per cent of reductions in total payroll, including increase per hour to efficient workers		18.8

Output and Locomotive Repairs

	1st Year	2d Year	Per cent
Light repairs	147	184	25
Heavy repairs	15	24	60
General repairs	16	22	37

In the case of machines two angle shears demonstrated an increase in efficiency steadily developing from 64 per cent to 120 per cent. The tons per man per hour show 100 per cent increase inside of six months.

On riveting the total rivets driven in one shop during a period of two weeks in December showed approximately 17,000 rivets driven, the first two weeks in March showed an approximate total of 39,000 rivets driven. The increase in rivets per man-hour due to a rearrangement of gangs was 61 per cent.

When the work was begun the number of pounds of good castings per molder was 1030.

Nine months later	1650
The cost per good ton direct labor was	$7.50
Nine months later	$4.80
The output in good tons was	1030 tons
Nine months later	3000 "
The per cent defective was	11.2
Nine months later	8.2

Work in one of the larger mills of the country was begun on January 14, with cost reduction as one of the objects in view. After a thorough inspection of conditions it was undertaken to reduce costs from $13.00 to $11.50 per thousand. The following tabulation shows the success of our efforts along this line.

Cost per Thousand			Total Reduction	Per cent Reduction
Jan. 14	Dec. 14	Feb. 16		
$13.00	$11.50	$9.00	$4.00	30.8

In a shoe factory the efficiency of routing was increased from 62 per cent to 100 per cent, the time being cut as follows:—

	Minutes
Vamps	405 to 215
Quarters	500 to 277
Linings	207 to 137
Uppers	150 to 147

In the same plant absenteeism was reduced from 15 per cent to 4 per cent. Labor turnover was so reduced that $610 a week or $31,720 a year was saved.

In a woodworking plant standardized ripping, cutting off, re-ripping, re-sewing on a compound quantity-quality basis resulted in a 33 per cent in output and saved nearly 50 per cent of the cost. As a result of the work done in this plant, which was a very large one, it was able to

run at full blast throughout the business depression, while several of its rivals failed.

In a department store the cost of deliveries was reduced from \$.08 to \$.05 per stop. Service time (waiting on a customer) was reduced from 4 to 1½ minutes for cash sales and 2 minutes for charge sales. Mistakes were reduced from 1200 per month to 250 per month.

At Hog Island two men punched 6000 rivet holes per day where it had before required 6 to punch 3600. Average riveting costs were reduced from \$.20 per rivet to \$.076.

In a steel plant economies were effected as follows:

Riveting—		
No. gangs reduced from	12 to	5
No. rivets per gang per day	400 to	1050
Cost per 100 rivets in	\$1.60 to	.75
Structural Work—		
No. men	475 to	290
Av. tons per man per month	4.90 to	12
Total no. tons	2450 to	2250
Payroll	\$35,000 to	\$10,000
Payroll cost per ton	\$14.00 to	\$4.50
Steel Castings—		
No. lbs. good castings per molder	1050 to	1700
Cost per good ton dir. labor	\$7.50 to	\$4.80
Output—good tons	1100 to	3000
Per cent defective	11.10 to	8.10

The cost per ton on fire escapes was cut from \$13 to \$6 in another plant. In another molders were making 16 side frames a day. Standards were set for 24 and within a month they were making 22. Standardization in the yard resulted in reducing the crew from 96 to 12 men in less than a year. The reduced force handled 3600 tons instead of 1800. Wages were increased 15 per cent. The painting crew was cut from 19 to 7 men, the cost being cut from \$0.25 per ton to \$0.11 per ton.

In another large steel plant, belting failures were cut from 31 per month to 8 per month. In the same plant men in the switch stand shop on piece work were less than 60 per cent efficient. The work was standardized, with the result that two months later the crews were averaging 70 per cent. In another month they were up to 90 per cent and eventually were brought up to 100 per cent. This increased the pay of the men about 25 per cent and cut the cost of manufacture about 40 per cent. In the switch shop the men averaged 44 per cent efficient when the work started in July, 65 per cent in August, 85 per cent in September, 90 per cent in February. Eventually the average reached close to 100 per cent.

TYPICAL STANDARD TIMES FOLLOW

	Unit	St. Time Minutes	Old Cost	New Cost	Saved Dollars
Grinding switches	100	56.1	.21	.1728	.037
Grinding sockets	100	189.0	1.18	.67	.509
Forging S. braces	100	40.25	.612	.354	.258
Forging I. braces	100	55.2	.878	.424	.453
Bending Sw. plates	100	152.	3.18	1.84	1.34
Stoving S. F. B.	100	180.4	3.61	2.05	1.56
Counter sinking—12 holes.	1 Plate	4.31	.031	.0189	.0125
Drilling —18 "	"	14.52	.170	.063	.1072
Threading bolts	100	47.9	.21	.163	.0468
Tapping B plate	100	44.	.185	.137	.332
Welding	Bar	40.3	.74	.40	.332
Bending	"	20.8	.33	.144	.186

In an establishment making ladies' garments the number of garments made was increased from 5500 to 8800 per week—an increase of 60 per cent. Workers were reduced at the same time from 1250 to 950 or 25 per cent. Wages were increased 25 per cent—20 per cent more than the average wage in the district. Quality was improved. Profits were increased $360,000.

In one plant—a machine shop—when standardization

work was begun it was found that men could have made four times the prevailing rates on existing piece rates if they had dared let themselves out. In an axle plant where I did some work one workman sold the pieces he didn't dare turn in to his successor for $17. In the same plant a man who quit volunteered the information that two and a half cents apiece was enough for the work for which he had been paid twelve cents—"because he had it in for the fella followin' him on the job." The antediluvian rate guesser promptly reduced the rate, in spite of which the "fella" made $8 per day without any trouble. In another machine shop men could have made $18 a day but only dared earn $4.50.

Engineers standardized the stores and order control in a moderate sized printing plant with the result that $10,000 was saved immediately on some paper orders and the company doubled its business within a year.

An investigation of conditions at a large shipyard showed that 350 men out of a payroll of 1800 did not exist. When the engineers secured evidence of the superintendent's guilt their office containing the proof was burned. In another plant it was discovered that a regular traffic in stolen brass existed. The workmen threw it on the floor, the cleaners threw it over the fence and a junkman hauled it away. In another plant my men discovered that a high labor turnover—over 600 per cent —was due to a deal between the superintendent and an employment agency. The employment agent got a dollar from each man the superintendent hired and the superintendent got a quarter. Whenever the superintendent wanted an extra dollar he fired four men and phoned for four new ones. None of these things would have been discovered except for the very careful check up which

is part of the survey preceding the installation of scientific management.

Teamsters employed by a large company whose principal business was warehousing and handling were found to be spending more time waiting than in loading, hauling or unloading. The work was planned and scheduled and operation costs were cut 25 per cent.

In a glass plant two men were put on an important operation that had been performed by six boys. As a result breakage was reduced 25 per cent.

In a bridge shop working on structural steel, 527 men were averaging 4.86 tons per man per month. As the result of a month's work on the part of an engineer, the output per man was raised to 13 tons. The shop output was increased from 1854 to 4000 tons per month. This output has been maintained for more than 7 years.

A foundry which was turning out 950 lbs. good castings per man per day was increased to 2200 lbs. per man per day and has run over 4 years at this output.

A machine turning out 79 kegs of railroad spikes per day was in 60 days brought up to 124 kegs. Standardized gang work in a foundry increased the actual molding hours from 5.8 to 8.8 per day. The efficiency of the workmen was increased from 55 to 94 per cent without the use of bonus.

To secure maximum results the work should begin with a careful analysis of the whole business, beginning with the balance sheet and profit and loss statement. Total earnings should be contrasted with the total investment and each should then be broken down so that the earnings of fixed assets in the various departments may be compared in the form of percentages with each other. Sources of profits should be scrutinized at the same time

in order to discover which goods are profitable and which are unprofitable. Once this analysis of the business is made, the lines along which economies can probably be effected begin to be evident. Plans can be laid to liquidate overcapitalized sections of the business in so far as circumstances will allow and either to discontinue unprofitable lines or to take steps to make them profitable.

The analysis of unprofitable lines leads to a consideration of markets and of production costs. If prices cannot be raised, manufacturing costs can often be reduced by careful and systematic attention to detail. Most American plants are overequipped and overmanned and undersupervised.

The work of reducing production costs begins with a general overhauling of the production records. This does not mean increasing the number of records. In fact a good deal of the work of competent industrial engineers for the last few years has consisted of quite the opposite. During the war industry was infested with systematizers who burdened industry with printed forms. In addition most industries have a lot of creative clerks who seek self-expression and praise from the boss—by inventing new and weird forms of various sorts. Very often the boss orders certain information to be prepared once and overconscientious subordinates continue to turn it out indefinitely and elaborately. Such weeds are exceedingly hard to root out unless a systematic effort is made and the situation is dealt with ruthlessly and impartially. Such a crusade is best conducted by an outsider whose destiny is not dependent upon internal plant politics.

Once simple adequate records are introduced, facts begin to come to the executive in such form and quickly,

enough after the event they describe has happened, so that in most cases simple executive action is able to effect immediate savings. Furthermore these records permit progress to be accurately measured, which is always an incentive to further progress.

Meantime the engineer has surveyed the different departments, has become acquainted with the foremen and a good many of the workmen. If he is the right sort they begin to come to him with their troubles and it is not very long before he is in a position to form a pretty accurate idea of just where improvements can be effected. From then on his work is partly educational and partly devoted to the erection of a mechanism which will, by the collection, compilation and correlation of basic facts make the best way of doing each piece of work evident and easier than some more costly way which has become a habit. This work on occasion covers everything from motion study of a workman on a specific job and production control to the division of the president's working day between administrative and executive duties and the introduction of a standard method of determining a financial policy.

On one such installation I made 166 written recommendations in a year and a half. Every one of them was signed by the general manager and so became a written order to and standard practice for the entire organization. After the first few recommendations were presented to the general manager there was practically no hesitation about signing them because he knew that the value of the innovation had already been made clear to everyone seriously affected—that each one had been "sold the idea"—before the recommendation came to his desk.

This installation effected savings in three factories amounting to $180,000 per year without counting the additional profits from increased saleable output. On this latter basis earnings were increased $375,000 per year. This was accomplished by betterments of the sort listed below:

	Per cent	
Machine breakdown reduced	58	
Furnace time reduced	47	
Demurrage decreased	68	
Planning efficiency increased from 78 per cent to	98	
Excess men decreased	42	
Labor turnover decreased (negroes increased from 9 per cent to 35 per cent of force)	47	
Productivity per workman increased over	25	
Saved by bonus, etc.		$45,000
Coal saved		$39,000

Costs were available on the 8th—factory costs on the 2d of the month instead of on the 20th—or later.

In this same plant the labor turnover which averaged 570 per cent in 1916 and reached 930 per cent in August of that year had increased to 750 in May, 1917, and seemed likely to reach 1000 per cent when the season really opened. Modern personnel methods and the bonus reward were introduced in July. From then on the turnover decreased steadily to 240 per cent in October *and remained below 300 per cent all during 1918* when industry was drained to the dregs by the calls of the American Expeditionary Forces. This was not accomplished without heroic measures including a labor survey of the locality, the introduction of experts to teach the foremen how to handle the new type of labor, and similar expedients, but the plants were not only kept going but turned out more goods than ever before.

The coal saving was effected by the introduction of recording pyrometers, technical control and a bonus sys-

tem which paid the furnace men—not more than a third of whom could understand English—on a basis of coal and labor saved and of the increase in the quality of the product. Quality was increased materially, earnings were increased about 40 per cent, furnace output was increased over 45 per cent and coal to the value of nearly $40,000 a year was saved at a time when labor and fuel were both of extreme value to the country.

The same methods introduced into a plant employing about two hundred men resulted in annual savings as follows:—

Increased profit from increased output	$61,775.00
Reduction in labor cost	42,465.70
Coal economy	14,500.00
Return from betterments recommended	26,272.00
Total economies	$145,012.70

A survey of a small machine shop which required less than two weeks' time upon the part of the engineer resulted in a saving of $21,060 per year as follows:—

Release of rented space by rearrangement of plant	$1,800
Reorganization of tool room	6,120
Readjustment of piece rates—approximately	10,800
Reorganization of inspection	2,340
Total annual economy indicated	$21,060

In a large woodworking establishment the introduction of a system of order control resulted in:

1. The time required for sales orders to pass through the general office being reduced 86 per cent.

2. The percentage of shipping promises broken being reduced to 45 per cent.

3. The average time to process an order through the factory being reduced 8 per cent.

4. Shortages in shipments being reduced 80 per cent.

Instances of this sort covering work with which I have been personally familiar or work done by men whom I have known personally and with whom I have been associated might be cited indefinitely. Most of them are the result of the application of the scientific method by an engineer to shop management. Application of the scientific method to any problem in industry, as in any other field, insures a decision based upon fact instead of upon opinion. Once the facts are collected in sufficient detail and arranged in the order of their importance the problem settles itself. There is no room for argument. That is why management based on opinion is so inefficient—the best arguer is usually the worst observer and he gets his way when he shouldn't—to the detriment of the business.

The same methods which have succeeded in the management of the shop have been applied to sales management and to financial management, although in both cases the element of judgment and the trading instinct play a larger part than in shop management. Furthermore, the usual engineer prefers to deal with things whose actions and reactions are known and certain rather than with people—who are at best uncertain. Finally, very few engineers are commercially minded or have had the business experience in the higher administrative and executive positions which is necessary in order to assist industry in problems of financial and sales management.

To show what can be accomplished by the application of these methods to an entire business, we quote the following from a report which was rendered after slightly more than a year's work in a large steel plant:

"1. On the basis of output per man in the various

departments the productivity of the working force—from December to August—was increased 27 per cent in the Open Hearth, 52 per cent in the Blooming Mill, 5 per cent in the Rolling Mill, 70 per cent in the X Department, 77 per cent in the Forge Department and decreased (owing to partial shutdown), 16 per cent in the Y Shop. This amounts to an average increase in productivity of 38 per cent which is equivalent to a decrease of 217 men.

"2. Capitalized these labor savings amount to $13,850 per year in the Open Hearth, $18,000 in the Blooming Mill, $12,950 in the Rolling Mill, $171,000 in the X Shop, $17,750 in the Forge Department and to a loss of $15,400 in the Y Department. Altogether the net savings in labor total $218,150.

"3. In addition to these economies there were savings in materials and supplies sufficient to increase these savings to:—

Department	On Basis August, 1922	On Basis of Attained Production
Open Hearth	$13,850	$13,850
Blooming Mill	18,000	18,000
Rolling Mill	12,950	12,950
X Shop	165,500	218,400
Forge Shop	46,580	147,000
Z Finish	4,266	4,266
Stores Control	33,000	33,000
Saw Shed & Roll Turn	2,019	2,019
Total	$296,165	$449,485

"4. Your own organization was responsible for these savings. Our work consisted in acting in an advisory capacity and in assisting in installation work covering such matters as:—

A. Standardization of—

1. Product
2. Machines

3. Labor
4. Methods

B. Production Control

C. Material Control

D. Equipment and Labor Control

E. Organization

F. Costs

G. Administrative Control, Budget, Financial Forecast, etc.

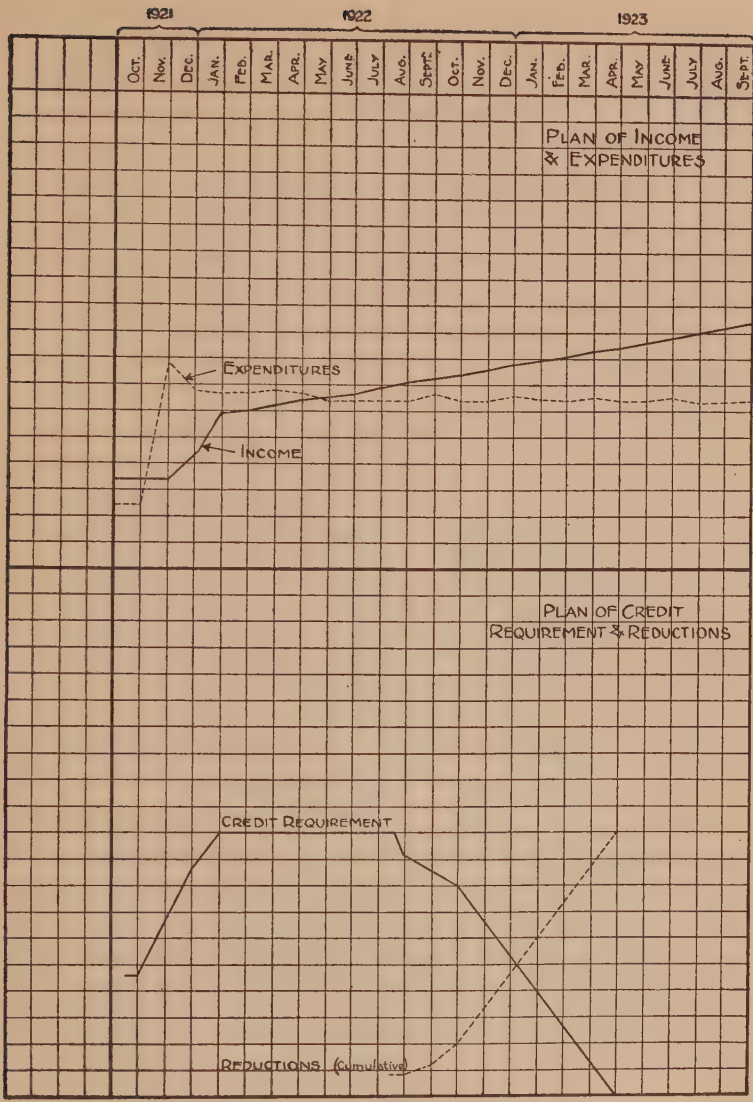
"5. Sales for August amounted to $298,448.10, 33 per cent increase over August of last year and 70 per cent over the average of $175,000 per month for last year. Sales during the first eight months of this year amounted to $2,218,000—more than total sales for the entire previous year—and averaged 59 per cent more per month than that year.

"6. Earnings for August amounted to 20 per cent of the capitalization—at the rate of a little over $200,000 a year as against a loss of $345,000 last year.

"7. An analysis of expenditures shows an increasingly careful and able management as demonstrated in detail in our Administrative Control Report of September 27.

"8. An analysis of your financial condition based upon the ratio charts in the Administrative Control Book shows a state in which conditions closely approximate the standard set."

The accompanying chart shows how a financial difficulty was solved. A certain manufacturer had an excellent balance sheet—from the technical standpoint of ratios—practically no liabilities, and receivables much in excess of his payables. Yet he could secure no cash to



FINANCIAL FORECAST OF MACHINE TOOL COMPANY.

meet his payrolls and material bills. His principal difficulty was that he was selling machines on the installment plan with insufficient working capital—so that every time he sold a machine for a thousand dollars he went just so much deeper in the hole. He received only two hundred dollars cash in payment and the difference between his sales price and his profit had to be paid out for labor and material. We determined accurate production costs and worked out this chart to show how long it would be before the incoming tide of monthly installment payments plus first cash payments would cause his cash receipts to exceed his cash outlay with sales figured on a conservative basis. Then we sent him, armed with these reliable data, to a firm which made a business of financing manufacturers who sold on the installment plan and he was relieved of his difficulties.

The books of another firm, which had built a large plant during the war and which had an old established business, showed sales in dollars during the years following the war in excess of those which preceded it. When these sales were analyzed and reduced to the number of units sold, it at once became evident that the business was slowly dying on its feet. A competitive analysis was then made of its other products, prices, probable costs, values, sales methods, advertising space carried, etc., being compared in detail with those of rivals. As a result it was found that a patented specialty universally used could be placed on the market for half the price of that sold by its rivals. The company made a sales drive on this and within six months turned out the biggest quarterly sales they had ever had, in spite of general business stagnation throughout the country.

In a certain town there were two similar plants which

Progressive assembly in an American motor plant.

were hit by the last depression at almost the same time. One was conducted conservatively, keeping to its single line of trade, and lost nearly a million dollars the first year of the depression. The other after an analytical market survey diversified its product specializing on products the least likely to be affected by the depression, and lost less than a quarter of a million. The plant that diversified its product was earning good returns the next year, while the first plant which kept all of its eggs in one basket did not begin to earn until a year and a half later.

A business whose ratios of current assets to current liabilities, of reserves to total assets, of fixed assets to net worth, of sales to fixed assets and the like were almost ideal was shown, when charted, to be trending in a dangerous direction. An analysis of working capital and certain other factors disclosed a condition closely approximating that which prevailed just before one of our most spectacular industrial failures. As a result radical changes were made in the financial policy of the company—the general manager went out on a personal collection tour—and the company was saved.

A certain very large company was in the hands of the banks. Some ten different reports had been rendered by various sorts of experts but no one had been able to boil the whole situation—which was exceedingly intricate—down to the few simple essential facts necessary to make constructive action possible. After some weeks of analysis the whole situation was put down on paper, was digested into conclusions and then into a three-page summary, as a result of which a reconstruction committee was appointed and certain other steps taken which are now resulting in getting the company out of its difficulties.

Thus the work of the industrial engineer has progressed, from Benjamin Franklin timing the frontiersman felling a tree, through production management, employment management to sales and financial management. The industrial engineer of today is the business doctor, a business man equipped to analyze a business, to collect the facts, to arrange them in the order of their importance, to draw correct conclusions as to what is needed—in a word, to apply the "scientific method" to industry and commerce in all its branches. If he then possesses the personality and the diplomacy to sell his conclusions to those whose hands control the destiny of business and to assist in carrying the determined policy to a successful conclusion, there is almost no limit to what he can accomplish.

Scientific management is here to stay—perhaps not in the form which filled the dreams of the early pioneers of the movement—but in some form which embodies the principles and the best of the mechanisms that these pioneers gave with that which progress has added. If this were not so, why would the larger banks each maintain an industrial engineering department? Why are thousands of young men studying administration and industrial engineering in our great universities? Why would one industry after another add an industrial engineer to its staff? There is no doubt as to the great good scientific management will accomplish when it is honestly and ably applied with the cooperation of an intelligent management and an open-minded honest working force. More and more industries are realizing this fact and business administration has become a profession.

CHAPTER XIII

SCIENTIFIC RESEARCH AS AN ASSOCIATION ACTIVITY *

H. E. Howe

It is somewhat discouraging to think how slow industry has been to avail itself of the benefits of science and to give it a real opportunity to demonstrate its potentialities. Many have been signally successful because they have seen the possibilities through an alliance with science, and yet others have stood by marveling at their success but blind to the example set before them. There has been no lack of men to urge the importance of science in industry. Pasteur, whose remarkable discoveries saved France a sum estimated as far greater than the indemnity paid to Germany at the close of the Franco-Prussian war, said, "In our century science is the soul of the prosperity of nations and the living source of all progress. Undoubtedly the tiring daily discussions of politics seem to be our guide—empty appearances. What really leads us forward is a few scientific discoveries and their applications."

Ten or twelve years ago Robert Kennedy Duncan pointed out that, "During the next five years the small manufacturer who is swept out of existence will often

* An abstract of this chapter was printed in *the Journal of the American Ceramic Society,* Vol. 7, No. 6, June 1924.

wonder why. He will ascribe it to the economy of large scale operations or business intrigues or what not, never knowing that his disaster was due to the application of pure science that the trust organizations and large manufacturers are already beginning to appreciate."

Still more recently our daily press has become interested in the achievements of research and has conveyed to the public in popular language stories of many wonderful accomplishments. It ought not to be necessary to reiterate the facts relative to the position of scientific work in industrial progress, and nearly anyone can draw examples from his own experience to prove the futility and false economy of continuing to wait for chance discoveries. It is true that many of our great discoveries have appeared to be by chance, but it can be demonstrated that these were made by trained observers systematically searching for new facts. And while the discovery may have been quite different from that sought at the moment, it would have passed unnoticed but for the scientific method being employed.

It is also disappointing to find how superficial is the interest of many manufacturers in scientific research, even though its place has been demonstrated in their individual cases. Unfortunately at the first appearance of a small cloud on the horizon, many concerns begin a program of retrenchment by closing their scientific laboratories, thereby stunting the growth or entirely destroying the only department of their organization which, if correctly conceived and properly managed, remains an anchor to windward under all conditions. This is especially likely to happen in cases where industries have become sufficiently prosperous to attract a new group of capitalists, who gain control. The banker is often un-

able to comprehend what it is all about, vaguely believing that all necessary research and development have been completed, and that the best way to show a quick profit is to abandon research programs upon which the industry has depended for its establishment and progress.

To gain the greatest benefit from applied science, individual manufacturers should establish their own research and control laboratories. These laboratories should be well equipped and manned, made attractive places to work, be adequately supported and genuinely considered an intimate, integral, internal part of the organization. A laboratory can become more important than the sales department or the advertising department, and there are instances where far-sighted executives have not hesitated to rebuild their plant as often as necessary and to scrap equipment in favor of new devices, but they have taken greatest pains to maintain their technical staff intact. The Hadfield Steel Works in England have actually become attached to the research and control laboratory rather than the laboratory attached to the works.

Every industry finds it necessary to engage upon fundamental work, work in the field of pure science, upon which the so-called practical work or technology depends. Occasionally, indeed often, industrial laboratories undertake this work on their own account, but we are coming more and more to appreciate that these are common problems, that they are so fundamental that the resulting data interest may separate concerns, that the work involved is so extensive that the individual corporation is seldom justified in doing it as thoroughly as is required at the sole expense of its stockholders. The results when obtained should not be left unpub-

lished, since their disclosure can repay only in part the debt which any organization owes to science. The fundamental data determined can be applied in the way suited to the problems of the individual concerns without regard to the interests of the others in the group, and the organization best equipped with scientific men is in position to gain the most from the new knowledge. Fundamental data, therefore, do not of themselves alter the relative positions of competitors. It is the ability to apply the information that makes the difference between the success of these rivals.

An appreciation of these facts has led to trade associations engaging upon programs of scientific research, and indeed some associations have been formed for no other purpose. Perhaps the greatest publicity has been given to the efforts in Great Britain to form research associations. The advantage gained early in the war by Germany, due largely to thorough organization among her scientific men, and the confidence which her manufacturers have always had in science, impressed itself upon Great Britain. She saw the necessity of meeting such organization with an organization of her own scientists and set up an Advisory Council of Scientific and Industrial Research. The results obtained were so important that the Council has become a department of the Government, known as the Department of Scientific and Industrial Research, answerable to one of the cabinet ministers. This plan has been followed with some slight changes by the various English possessions. In Great Britain a million pounds was set aside by the Government to encourage trade associations to put money into the work of organization, laboratory equipment, and staff. Pound for pound has been the

plan for such organization, and more than twenty-five associations have been formed, licensed, or are in process of formation. Much success has attended these efforts, and in general the trade association has assessed itself on a basis of some convenient unit, as, for example, the number of spindles in the cotton plants, or, in metal trades, dues based on gross output of castings. Some of the trades had no information to contribute to their new association, but the foundrymen took the most forward view of any and not only pooled financial resources, but also their so-called trade secrets and experience for the benefit of the whole trade. A further grant of a million pounds has been recommended by the Government for another five-year period.

In America it has seemed best for trade associations to conduct their scientific activities without the aid of government money, for with the use of public funds there always goes a certain amount of necessary control which becomes irksome. In general, trade associations here have been formed without regard to scientific work and have undertaken this work only after a long period of education, during which it has been demonstrated that even competitors can work harmoniously on a scientific program, provided only that the problems selected are sufficiently fundamental to interest all members of the association and avoid the necessity of some leader in the group disclosing information which he considers stock in trade and strictly confidential.

Let us examine something of the experience of a few of our trade associations, indicating a little of their method of raising funds and other details. The avowed object is to show such a wide interest in the subject and such success for those who have proceeded

on a good plan as to demonstrate clearly the advisability for any association to lay out research programs and start work. It is not the intention to cite the associations in chronological order, nor is the claim made that all in America have been included in this survey, but enough experience can be cited to demonstrate the soundness of the contention.

A large number of associations begin their work with standardization. The United States Bureau of Standards has prepared a report on the standardization work going foward in one hundred and two trade associations cooperating with the Bureau. Mr. Wharton Clay presented a paper on March 1, 1920, before the Western Society of Engineers on "Engineering and Trade Association Work" in which he states that in preparing his paper he canvassed more than six hundred trade associations. A recent publication of the Department of Commerce lists more than two thousand national and international trade associations in the United States. The diversity of subjects which have been studied with the object of cutting costs and bettering trade conditions through standardization will be illustrated by the following list: Paint, varnish, shellac, gas, steel, cement, concrete mixers, sand and gravel, metal forms, concrete pipes, gypsum, lime, metal lath, clay products, hollow tile, steel sash, paving brick, asphalt, handling, lumber, preserving, cooperage, boxes, silk, implements and vehicles, fertilizers, tanning, electricity, elevators, acetylene, founders, gears, tools, brass, refrigeration, heating, boilers, asbestos, explosives, paper, wood wheels, motors, automobiles, canning, and glass.

Such work has been of real value, as may be illustrated by the work of the Glass Container Association.

When the laboratory undertook its work it found 210 styles and sizes of prescription bottles alone. These have been reduced to 20 without inconvenience or loss of business.

In the rubber boot and shoe business there are now about 15,000 styles and sizes of overshoes, rubbers, and boots demanded by the trade. This would seem to offer an opportunity for standardization and simplification.

Trade associations vary between wide extremes in numbers of members. The California Fruit Growers' Exchange is a cooperative, non-profit, non-capital stock corporation composed of 12,500 growers. The research laboratory was organized primarily to develop methods for the conversion of the lower grades of citrus fruits into saleable stable products. The laboratory is operated at an approximate cost of $12,500 per year and three chemists are employed. In addition to the important problems of profitable utilization of that portion of the fruit crop which will not stand the long freight haul, the laboratory studies problems of insecticides and fungicides and other phases of fruit growing, utilization transportation, etc. Funds are obtained by an assessment of so many cents per box of fruit marketed through the exchange facilities, and at the end of three-year periods adjustments are made to cover the exact cost of operating the exchange without profit. The laboratory is financed from this fund by direct appropriations. Between thirty and forty thousand tons of citrus fruits are now consumed annually in the production of citric acid, lemon oil, orange oil, and orange vinegar. As a result of the work accomplished in cooperation with Government agencies, the research laboratory has won an established place in the citrus industry.

The other extreme is illustrated by the Magnesia Association of America, which has never consisted of more than four members. These have been the manufacturers of magnesia products who have had for their purpose the determination of constants and engineering data relative to the use of 85 per cent magnesia as an insulating material and the education of engineers, architects, and plant owners to the importance of using insulating material in accordance with scientific data. The income of the association is secured by a flat percentage tax laid on the actual goods shipped, the value of which is put at the list price. The association is operated on a budget system and income has varied, depending upon the extent of activities, from a minimum of $20,000 annually to $125,000. The secretary-treasurer of the association makes periodic audits of the books and accounts of the member companies, determines the amount of merchandise shipped during a given period, levies the tax, collects it, and pays the bills, all in such a manner that no one member knows the amount of contribution or the percentage of the whole business done by any of the other companies. This association finds it advantageous to conduct its scientific work through a fellowship established at the Mellon Institute of Industrial Research, at the University of Pittsburgh. The findings of this research are given wide publicity, generally through the engineering and technical papers, but to some extent through popular magazines and directly by mail.

Among the most successful has been the National Canners Association. The fees for membership are one per cent per case of canned goods manufactured, and in addition to the support of the secretary's office and

general machinery of the association, including commodity advertising, the income is devoted to certain lines of informational work and scientific research. This includes the study of agricultural problems regarding the care of canners' crops, physiological research including the study of food poisoning, and technological research (chemical, physical, bacteriological) on production problems and new products. During the canning season an inspection and production service is maintained and it may be said that through the efforts of the research laboratories the entire industry has been put upon a higher plane. The inspection now self-imposed is in some respects more strict than that first imposed by the Government which was resented at the time. Extensive studies have been made of the relation of tin plate, used in making packers' cans, to experience with such packages, the heat penetration of canned foods during processing, the relation of acidity, time and temperature factors in destroying resistant bacteria, and a study of the fundamental causes of certain types of discoloration which sometimes occur in canned foods. As conclusions are reached, valuable publications are issued and the laboratory carries on cooperative work in several important directions. In some cases arrangements are made for the work itself to be done in laboratories outside the association, but in cooperation with it. In matters of education, trade promotion, improved forms of reports, standards and research, the laboratories of the association and the association itself cooperate fully with both state and federal governments. Appropriations for single items of research have become as large as were the original allotments for the entire research program (about $30,000).

The Container Club is an association of corrugated and

solid fiber box manufacturers who maintain a fellowship at Mellon Institute. The members have been well satisfied with the results secured and are confident that real progress has been made.

Recently the Eastern Clay Products Association has undertaken research upon the study of the manufacture of salt glazed vitrified clay pipe. Results have not yet been reached, but it is gratifying to find that those interested in one of the world's oldest industries—ceramics—have found that it will be well to supplement many, many years of experience with scientific data.

The Underwriters Laboratories in Chicago with branches in other cities have become a national institution. About 150 people are employed in the Chicago laboratory in which approximately $225,000 has been invested. The laboratories were established and are maintained by the National Board of Fire Underwriters and are operated for service and not for profit. The object is to bring to the user the best obtainable information on the merits of appliances, devices, machines, and materials in respect to life, fire, and collision hazards, as well as the prevention of theft and accident. The work was undertaken in the hope that the enormous and disproportionate loss of life and property by fire and accident might be reduced, and it is believed that through the efforts of the laboratory and its backers much has been achieved in this direction. These laboratories have cooperated with others interested in the field and as a result better structural practice has been adopted in some trades, a whole series of safety doors, cans, and other devices have been developed, and a labeling system established which is a great guide to the public in choosing items for particular purposes. Among other research problems successfully

attacked has been the testing of structural columns under actual fire conditions. The mill timbers, cast iron columns, fabricated steel, reinforced concrete and other types of supporting columns have been heated to controlled temperatures in special furnaces, quenched while hot and kept loaded throughout the test so that performances under actual conditions could be predicted with accuracy. In addition to the appropriations made for the maintenance of the work, a considerable income is derived from a label service and a charge made for certain types of inspection and testing and for research undertaken at owners' cost. The laboratories are unusually well equipped and there is no doubt but that the National Board of Fire Underwriters considers this venture exceedingly worth while.

The American Malleable Castings Association realized that the considerable number of inferior castings being made by the trade interfered decidedly with development of the market for malleable castings. The association formed a research committee, equipped a laboratory, secured a competent director, and began the work of so improving the products of every member of the association that malleable castings would sustain a reputation for high, dependable, and uniform quality. The work has been going on for the last ten years, which is a testimonial to the high regard which the members of the association have for research. The average ultimate strength of the castings made by association members has actually been increased from 38,000 pounds at the start of the work to 53,000 pounds, while the elongation has been raised from an average of about 4 per cent to an average of over 15 per cent. The members who formerly made the best castings continue to do so, but the industry as a whole is

far better off and the work of the association in this direction has attracted attention in most of the countries abroad. The association spends about $150,000 per year in research, and other work on control, in addition to research, is conducted at the expense of individual members for their benefit. This sum does not include advertising or the expense of members attending monthly meetings. The various plants are visited each month to inspect castings, and when quality is found to be deteriorating specialists go at once to see the trouble and endeavor to solve the problem. Inspectors also see to it that the castings shipped by the producer are equivalent in quality to the test bars submitted to the laboratory. A research committee meets the second Tuesday of every month in Chicago, followed by a regular meeting of the western members of the association. The third Friday of each month finds the eastern members meeting in New York City. Joint meetings of eastern and western members are held quarterly in Cleveland.

The work of the research laboratory of the National Association of Corrugated and Fiber Box Manufacturers consists in designing fiber containers for various articles and then testing them. The association finds it advantageous to cooperate with the Forest Products Laboratory at Madison, Wis., where a large revolving drum has been installed to test different types of containers under various conditions. An examination of the average car of parcel freight indicates something of the problems involved in minimizing loss and damage in shipment, while at the same time reducing the cost of containers. The work of this association has contributed greatly to the solving of these problems in which the research laboratory has played a major part.

The National Warm Air Heating and Ventilating Association conducts its research at the University of Illinois. The association appropriates about $8000 a year for the work and the money is obtained by assessments upon the membership which is divided into five groups determined by the amount of the members' sales and the character or grade of goods made. A plan has been devised which endeavors to care adequately for differences in value of goods made and volume of business done so that assessments are on an equitable basis.

When the research work in this association was started the warm air furnace industry was without reliable, unbiased engineering data. It is to correct this condition that the work has been undertaken and the association feels that it is meeting with success. The progress of the work is published in the bulletin series of the University of Illinois and elsewhere.

Various associations maintain independent research laboratories and besides there are many supporting research in institutions. Some find it profitable to do both. The Gypsum Industries may be taken as an example. The use of agricultural gypsum as a fertilizer, the relation of this gypsum in nitrification as a plant food, and for research on sulphur content of soils and rain water are subjects of such research.

The Clay Products Association is interested in the furtherance of the use of drain tile, wall coping, segmental block for sewer construction, flue lining and similar clay products. In addition to research at Mellon Institute the association maintains a physical and chemical laboratory in Chicago where many problems directly affecting the use of their materials are studied. The association is also engaged in the preparation of a

handbook for the use of engineers, architects, and others, and feels that its scientific program is well worth while. The income of the association is based on the amount of goods sold and the budget includes items for the scientific work decided upon for the year in question.

In the American Gas Association most of the income is derived from membership dues, of which there are two classes—company members and individuals. In addition, a charge is made for certain special service rendered to members and there is some revenue from the sale of publications. The association is rendering a very definite service to its member companies in the matter of engineering service and has upon its staff two members available for either field or installation work. Operating problems, industrial fuel development, heating standards, the examination of gas appliances and gas consuming devices as regards fire hazards, efficiency, etc., indicate some of the lines of endeavor. The association through its various divisions has done much to bring about a new spirit in the gas industry, obtaining complete cooperation as well as intelligent and thoughtfully directed effort to make the gas business one of the leaders in America.

The Asphalt Association is one of the newer industrial groups, having been formed in May, 1919. The members are assessed \$100 annually as dues but no additional payment is made by them. Contributing members pay a lump sum yearly, fixed by the Board of Directors in general conformity with the extent of business done by them and benefits to be derived. This is generally an assessment varying from 32 to 40 cents per ton of paving asphalt sold. The association was formed to increase the market for asphalt in paving and in order to carry on its

educational program and do constructive work, it calls upon science. This has to do not only with asphalt itself but with the chemical and physical factors involved in its application, cooperation in designs for highway construction, and the behavior of asphaltic types of pavement under various conditions of service. There are still many problems before this group and their program is of interest to all, especially in view of the large sums now being spent throughout the country on various types of street, alley, and highway construction.

The Glass Container Association of America, while one of the newcomers in association research work, is already among the leaders. Here the problem is to develop a type of glass that will be better suited for a variety of containers, the object being to displace tin and other opaque containers in many fields. The influence of light passing through glass of various compositions upon the contents of the can or bottle is an important phase of the investigation which extends naturally to improved methods of packing and transporting glass containers.

The Paint Manufacturers' Association of the United States and the National Varnish Manufacturers' Association are organized along similar lines and both are interested in supporting an educational bureau. Income is derived from annual dues, the basis in both associations being the same. The dues range from $37.50 to $150 per member. An initiation fee of $25 is charged and the dues are for three classes of members, those rated at $50,000 or less, those between $50,000 and $100,000, and those having a rating above $100,000. The educational bureau is supported by five-year subscriptions which range from $50 to $10,000 annually. These are volun-

tary upon the part of members of both associations and any others interested in the work. The funds for the bureau are kept distinct from the treasuries of the two associations. The educational bureau has carried on research and experimental work for a number of years and published the results widely. It has studied special application of paint and varnish and has developed new compounds as, for example, a special paint designed to reduce the fire hazard of wood shingles. When a new formula is devised and developed to the manufacturing stage, it is the custom of the associations to grant licenses for its manufacture to members of the associations.

There are two research association activities in the textile field. The Silk Association of America has directed much of its attention to the conditioning and testing of raw silk. It has made important contributions to the subject and has performed a service in cooperating with foreign producers. This has led to silks being brought to our market in a condition best suited to our uses. Tests acceptable to both buyer and seller have been devised and there are many phases of silk production which have engaged the attention of the association. These include testing of dyes, researches upon the fastness of colors to sunlight, fundamental work upon the physical constants of the individual silk fibers, etc. The conditioning house makes a charge for the work done and is owned by the association. The work done is more satisfactory than was previously possible in a similar establishment privately owned.

The National Association of Cotton Manufacturers has given extensive consideration to research in the cotton industry, being spurred on somewhat by the success of

the British Cotton Research Association. The latter has been one of the most successful of the associations formed by trades under the auspices of the British Government. Beginning with a research committee, upon which were cotton mill men and scientists, a program has now been worked out for certain additional studies as an opening wedge to a larger program for the industry. A research secretary has been employed who in addition to doing a certain amount of service work will travel in order to learn at first hand those problems confronting the various members of the association which may be solved through applied science. The wool associations have expressed much interest in research but as yet have not been able to approve plans. The subject has also been before the association of textile finishers.

An outstanding example of the influence of science upon a long-established industry is to be found in the American Institute of Baking, which is one of the major activities of the American Baking Association. The institute is the outgrowth of an idea backed by one or two individuals who learned from personal experience what applied science can do for their own business activities. Some years ago one of the large bakers operating in many centers discovered that there was difficulty in producing the same quality of bread in various cities. After empirical experiments, the head of the organization became interested in the possibilities of scientific research, began with a fellowship, and learned first of all that the difference in his bread was due largely to the mineral contents of the water available in the various geographical locations. This led to the determination of the optimum conditions for the growth of the yeast and before long a yeast food or stimulant had been prepared

which not only proved efficient in making a uniform product possible but actually effected so large a saving of sugar, flour, and yeast as to be credited with more than a million dollars in a single year's activity. The enthusiasm of the instigator of this research supported by other far-sighted men in the industry has led to the formation of the American Institute of Baking. They became so enthusiastic that the question of establishing a research laboratory for the industry itself was brought forward by them and from a modest beginning the institute has now advanced to the place where it owns a building, is giving short courses for those either in the industry or about to enter it, performs a plant problem service, and conducts research on problems fundamental to baking. A bulletin on the technology of the business is being issued, and support has come to the project in such volume that a broad program has been made possible and is being put into effect. This experience of the bakers is even more interesting when we remember that by far the majority of commercial bakers would consider themselves unable individually to afford a laboratory or take on any expense which might not lead to immediate returns. The statement has been made that of the 26,000 bakers in the United States, only 7500 bake 50 barrels of flour per month, 2500 bake 200 barrels per month, and one baker requires a million barrels per year. Through the cooperative effort in which they are now engaged, the trade as a whole is able to avail itself of new principles and methods which otherwise would have been impossible. Through the combined efforts of scientists and experienced bakers we may still hope for a larger and more nutritious loaf for less money.

The Biscuit and Cracker Manufacturers also have their

association and a technical bureau. The initiation fee of the association is $50 and the annual dues $200 per member. The technical bureau examines a wide variety of raw materials entering into the production of biscuit and crackers, sends out a confidential bulletin service giving the results of its work, is in a position to recommend new procedures.

The National Electric Light Association is well organized, has a large number of active committees engaged in carrying out a national program and also sectional plans. The geographical divisions include Canada, Eastern, East Central, Great Lakes, Middle Atlantic, Middle West, New England, North Central, Northwestern, Pacific Coast, Rocky Mountain, Southern, and Southwestern states areas. There are special as well as general national committees and a technical informational service. The subcommittees are engaged upon questions relative to prime movers, problems with regard to lignite, gas, liquid fuels, waste fuels, by-products, etc.,—indeed all the various scientific and engineering phases of the great industry represented. The method of financing is by annual dues on various classes of members which are drawn from nine great groups. The dues are further scaled in accordance with the population served by the various classes or by the amount of gross revenue from sale of apparatus and by such other classifications as will result in equitable assessments.

The National Fertilizer Association has no research department, but its Soil Improvement Committee has established fellowships at several colleges where research work in connection with fertilization is carried on. There is a staff of experts who are constantly at work to increase the yields of farm crops. The committee gives in-

formation on the profitable use of commercial fertilizers, on improved means for increasing yields through better seeds, better cultivation, and improved handling of crops.

The American Society of Heating and Ventilating Engineers devotes about $25,000 a year to its research laboratory. The funds are raised by popular subscription and the work is done in cooperation with the U. S. Bureau of Mines, Pittsburgh laboratory. More than 20 definite research projects have so far been undertaken. Some of the work has been completed but much is still active. Twenty-five separate problems made up the research program for a single year, all of which are designed to produce results for the public good. No tests, experiments or research are conducted for compensation and it is intended to study closely as many phases of heating and ventilating and allied subjects as is possible.

The Associated Factory Mutual Fire Insurance Companies maintain laboratories where fire protection devices are examined and tested, first, for the purpose of recommending to member companies and manufacturing plants the best appliances, and second, to aid in the development of promising equipment. The Associated Factory Mutual Fire Insurance Companies consist of 20 mutual insurance companies and are really an association of the owners of about 4000 of the principal manufacturing plants in this country and in Canada, representing a value close to $6,000,000,000. Studies on the hydraulics of fire streams, the development of specifications for fire protective equipment, of the fire retardation properties of building materials, and studies on industrial processes with a view to reducing their fire hazards, are all a part of the program. As a result, fire loss in manufacturing plants has been steadily reduced, notwithstanding a general increase

in the hazards of manufacture and greater concentration of valuable materials.

The Association of Manufacturers of Chilled Car Wheels has for its purpose the advancement of knowledge concerning the manufacture and service of car and locomotive wheels by discussion, investigations, and reports of experience of experts and of members of the association. Information is gathered and distributed on the manufacture and service of car and locomotive wheels. When the organization was formed, every wheel maker had a special design of wheel. The association has succeeded in standardizing to four types designed for cars of different capacities. These four take the place of about 175 patterns. A consulting engineer is retained on full time and a physical laboratory has recently been installed to further the work of the association. There are 25 members of the association and funds are obtained based upon the capacities of the plants. Assessments in amounts of $5000 are levied when funds are required. The total expense of operating the association in 1922 was estimated at $40,000.

Some of the associations have combined research with service made possible through the laboratory work which has resulted in direct saving to the users of their materials.

The Portland Cement Association is another active group which represents more than 90 per cent of the total production of Portland cement in the United States. In 1905, they began to discuss a research laboratory for the association, but a definite plan of action was not decided upon then and funds were not available. From 1916 on, the present activities of the association have been developed, having to do principally with scientific, edu-

cational, and promotional work. District offices are maintained to give service to users of cement, and through the structural materials laboratory research has been carried on and has proved its value to manufacturer and user alike. A corps of engineers, chemists, and assistants give their entire time to the work and the results are published in the form of papers presented by them before scientific societies and in bulletins issued by the laboratory for general distribution. The annual budget runs into several hundred thousand dollars, which includes the cost of maintaining the service engineers in the various district offices. The research has to do largely with devising means for using local materials, and fundamental study on the part played by various components of concrete and cement, the influence upon strength of such factors as temperature and moisture during setting, excess water in mixing and similar factors. Assistance has been rendered in designing standard structures and in devising uniform rational construction practice.

In its effort to give the public better information on to follow up its educational work properly, the National Lime Association found that in even so old a material as lime there is much need for investigation and research. This touches upon the properties of the materials produced in the different quarries and with different equipment, while much time is spent on its peculiar application of lime in the more than 165 industries which find it useful. The investigational work of the association is conducted not so much in its own laboratories as in cooperation and collaboration with other institutions which have a common interest in lime. A considerable amount of work is done through industrial fellowships in different educational institutions, this work being directed jointly

by the director of the association and a representative of the institution concerned. The data obtained are published and distributed among those interested, whether it be lime for construction purposes, for agriculture, or for the chemical field. Funds are secured by assessment on the product of each member in the organization, levied at so many cents per ton of lime produced, the amounts being fixed each year by members in convention assembled.

The American Petroleum Institute derives its income from two sources, first, membership fees of ten dollars per member (meaning individual and not company members), and second, outright contributions by oil companies. The representative business units of the industry are invited to assess themselves voluntarily each year and make a financial contribution computed in accordance with a plan which takes into account gross receipts or annual turnover. The institute deals only with matters national or international in scope, and among the several departments is included one on technical research. The director of research has made a careful study of the principal problems confronting the producers and refiners of petroleum, has obtained wide publicity for them, is co-operating with various scientific bodies qualified to conduct research, and plans are in progress for obtaining funds so that the institute itself may engage directly upon some of this important work.

The Tanners' Council of the United States of America includes nearly all the producers of various grades of leather. Previous to the war, a research laboratory was established which has since been reorganized upon a broader plane and encouraged to proceed with fundamental work as contrasted with service work on raw

materials of one kind or another. Research begins with the biological changes which take place in the skin immediately following the death of the animal and the relation of these changes to the various tanning processes. Here and there research in tanning is being supported privately by firms representing the best in the industry. The council was instrumental in furthering a school where those in the industry might gain knowledge to make them better craftsmen. The council now has under consideration a comprehensive plan for the establishment of a school not only for craftsmen but for advanced students and for research through fellowships. The research and educational work is supported through direct appropriations from council funds. An appropriation of $110,000 has been made recently for a new research laboratory.

The National Wood Chemical Association, as well as a number of other groups, find it convenient and satisfactory to conduct their research through the means of a fellowship at an educational institute. Some of these fellowships have been in effect for several years and various groups appear well satisfied with the plan. A favorite method is to direct the research through an advisory committee of manufacturers appointed by the association. This committee meets occasionally to receive the reports of the fellow, discuss what has been accomplished, and suggest further researches. Much of the value of the work accomplished depends upon the manufacturer himself, who must put the scientific data to work in his own plant if he would receive the greatest possible benefit.

The Refractories Manufacturers' Association has been engaged in research for over five years, the original yearly

appropriation having increased about 500 per cent. At first, only problems of general interest were studied and this policy was followed for about one year. At that time it became evident that many of the research problems of the various companies required special study. These studies can be made by following certain definite procedures, but the results are affected by operating conditions at the various plants. The refractories industry, especially that branch which is devoted to the manufacture of fire-clay brick, does not work with a standard material. The physical properties of the clays vary as does the process of manufacture. It is this situation that limits the application of many of the results that may be obtained by research. Consequently, it was decided to make the research facilities of the association available to the members by the payment of a fee necessary to cover the expense of an individual investigation.

This latter field has been most profitable and popular for the results are immediate and have a definite application. The experience gained by studying the same problem at different plants has been invaluable and often has made possible the expression of an opinion or recommendation without additional study as the problem continues to arise in new locations.

There is an extremely large field in this industry for the study of conditions under which the product is used. As these studies progress certain facts become evident. In some cases the product is used with shameful ignorance as to how it should be treated, yet when ultimate failure results it reflects upon the producer. Careful study has developed information on many of the evil practices that are common. On the other hand, certain raw materials cannot be used for many purposes; the

shrinkage may be too high, the refractoriness too low, or the strength insufficient. In other cases, complete knowledge of service requirements enables the production of suitable ware.

As unforeseen development of this plan has been in connection with matters of a more business-like nature. An accumulation of extensive data is of great benefit in many of the everyday problems that come up, regarding specifications, tariff matters, trade development and similar examples. The centralization of data regarding similar products permits the formulation of policies that would otherwise remain undeveloped under conditions where each manufacturer is forced to protect his own interests without knowing how others may be affected.

Another active group is the Laundryowners' National Association. In few industries has research been able to accomplish more important results in so short a time. Through the research department, which maintains a fellowship at Mellon Institute, the members are kept advised regarding the best supplies to use from the standpoint of effect upon the goods treated, quality of work accomplished, and the net cost. A great deal has been accomplished in the conservation of textiles, the elimination of claims, and the general improvement of processes. The fact that the industry is engaged in research and is obtaining results that show in the product, has raised the plane of the industry, and this is evidenced by its being considered by other industries in a somewhat different light than formerly. An extensive service on everyday problems is maintained concurrent with the research work. The department of mechanical engineering has given attention to the conservation of fuel. In the future, it will give more time to structural engineer-

ing, the testing of new laundry devices, the design and layout of plant, ventilation, etc. The association is active in many other lines but has thought so well of its experience in scientific research that it is about to inaugurate the American Institute of Laundering as a means of correlating all its important activities and putting theories that have developed into practice in the commercial laundry. The research as now maintained will be continued, but much of the development work based upon research data will be done at the new physical and chemical laboratories to be included in the institute plan. Those who are devoting a great deal of time and thought to the project have in mind raising the general standard of the industry so that it will deserve the good will and confidence of the public. What has so far been accomplished through research indicates the great possibilities of complete success.

The achievements of scientific research in the packing industry have become a classic and are often used to illustrate how exceedingly profitable research can be made in commerce. It has come to be known that the profits of the packing business depend almost exclusively upon the utilization of by-products and this utilization rests absolutely upon work which has been done in the laboratories. Every packing house of any consequence maintains a research and control laboratory. In view of these facts it is particularly interesting to note that a concerted movement has been initiated by the Institute of American Meat Packers looking toward the establishment of an actual institute planned to meet outstanding needs. It is recognized that there is at present duplication of research work, that there is a limitation of research to such lines as may be expected to return a quick profit, that

the individual companies—and there are 257 of them in the institute—have their development limited by their own experience, that no effort has been made to systematize this industrial experience, and that the future is limited by the progress of the present. The industry is looking toward the establishment of a central distinctive home where technical men may be trained to succeed those now active in the packing industry, where by providing facilities for a broad training the executives of the future may not be specialists in such narrow fields as many departmental executives of the present régime are known to be.

The institute may become an organization which will combine the activities of a research institute, an educational center, a trade association, and an industrial museum. To quote from the plan submitted by the Institute Plan Committee, of which Thomas E. Wilson is chairman:

1. As a research institution, it should:
    a. Develop and systematize a body of scientific and practical data for the service of the whole industry.
    b. Carry on agreed researches into new scientific and practical problems common to all packers, without infringing on research along individual lines being done by specific companies.
    c. Conduct experiments on the extension of products and reclamation of materials (except where such experiments would infringe on original work done by some individual company).
    d. Collate and disseminate information concerning discoveries and developments having relation to the packing industry, without invading material developed by particular companies.

e. Conduct merchandising surveys and commercial research work.
f. Discover waste and means of eliminating it.
g. Test materials and equipment offered to the industry.

2. As an educational institution it should do at least three things:
   a. Provide broad but specialized collegiate education for young men intending to enter the packing industry, just as the Colorado School of Mines provides such training for young men expecting to begin their work in the mining industry.
   b. Furnish special training to intermediate sub-executives (prospective departmental heads) of promise already engaged in the industry.
   c. Conduct a continuation school for plant employees and junior office help.
3. As a trade association, it should continue to do what the institute is now doing in this direction.
4. As an industrial museum, it should provide space for permanent exhibits of models showing modern packinghouse operations, specimens and processes; and it should rent out space for exhibits of materials of industrial value, and for a permanent exhibit of packinghouse machinery and supplies—a sort of scientific museum and centralized market place, a gigantic permanent show window, conveniently located (being at Chicago), where packers from all parts of the country may come and view samples before making purchases and installments.

The National Lumber Manufacturers Association, the National Association of Macaroni Manufacturers, the National Pickle Packers' Association, Hawaiian Pineapple Association, and the Southern Pine Association,

are other examples of associations supporting scientific research work. Still other groups, such as the Interstate Cottonseed Crushers' Association, contribute toward research although not maintaining their own laboratory or fellowship. Still other groups of manufacturers who have not formed an association cooperate in sustaining scientific work on problems of common interest. This is sometimes done through a scientific institute founded for the purpose. The Crop Protection Institute is an example where the producers of raw materials for insecticides and fungicides, the manufacturers of these products, and the makers of machines used for their application work with the representatives of the sciences involved, in carrying out cooperative experiments. There is at least one example (Massachusetts) of the associated industries of a state turning to the laboratory for technical information.

Special pieces of research have been conducted by those interested in the raising, sale and distribution of coffee, by sugar interests, by textile mills which have formed themselves into a company for research purposes, and even department stores which have united upon a program of research in psychology and industrial relations.

Very often a number of companies become associated in a new corporation which then undertakes research on an extensive scale. This cannot properly be described as association activity and yet the research in question receives its impetus through the association of these companies under one holding company. The interesting work now being done by the General Motors Corporation, the American Writing Paper Company, and the Union Carbon and Carbide Company is examples.

In addition to all of these, there are a number under

consideration. The glue and gelatin manufacturers, the milk producers, those interested in alloys, in the development of pharmaceuticals, and in sulphur have cooperative research on their programs.

Having decided that research is of moment to an association, there naturally arises the question as to the plans which have been tried and found satisfactory. As previously indicated, many associations prefer to use their own laboratories, man them and direct the work. Other associations begin by supporting a fellowship at one or more of our universities. Some rely upon the excellent facilities of some of our commercial laboratories or consulting engineers. Others make existing laboratories in plants available for the problems assigned and may begin with a sort of informational clearing house on existing knowledge and state of the art as disclosed by literature. Societies themselves may be formed, like the American Bureau of Welding and the Crop Protection Institute, where all interested may meet on common ground and apportion the work, oversee it and through the means of committees, obtain funds from members, and conduct experiments without actually establishing a separate laboratory.

Another plan is that of cooperation with various government laboratories. Research associates are placed in these laboratories under the direction of the head of the bureau but with the program arranged with the assistance of an advisory committee representing the industry. At the Bureau of Standards in addition to research associates placed by single companies, scientists are maintained by the National Glass Containers Association, the Hollow Building Tile Association, Associated Tile Manufacturers, and the Gypsum Industries.

At the Bureau of Mines the cooperators include a number of Chambers of Commerce, individual companies, universities, and public service corporations. The Southern Appalachian Coal Operators Association and the American Society of Heating and Ventilating Engineers also work with the Bureau of Mines. The Heavy Clay Products Association and the Refractories Manufacturers have cooperated with the Bureau of Mines in an extensive survey of possible economies in kiln firing. In general the Bureau contributes to the work to be done there in the time of specialists, in housing the equipment and other substantial assistance. The results in all cases where government cooperation is involved are published at the conclusion of the work.

The Forest Products Laboratory, the Department of Agriculture and its various bureaus, and other Government agencies are frequently available to organizations conducting research where public good is involved.

Research can be successfully conducted by the association plan, whether the association be composed of a small or a large number of individuals. There is a precedent for nearly any type of association and there are many methods for securing research funds. In general these are based either upon the gross business done, the capital stock, the number of employees, items of equipment, or the number of packages of products shipped. Voluntary contributions form another somewhat less uniform basis.

There are facilities and plans for carrying on a research program to suit any association activity, and a start can be begun with a director of research who can survey the field, tabulate the problems and set up an informational clearing house, if funds are not available for a more extensive program. As money becomes avail-

able fellowships can be established, special problems assigned to individual laboratories, and in time, if desirable, a laboratory can be set up and maintained by the association for study exclusively upon its problems.

It is difficult to see how the modern business man individually and in association, can fail to utilize for his own advancement the various sciences which have contributed so greatly to the success of others. Some of the advantages include attracting a better class of men into the industry and executives themselves find their business much more interesting after research is made a part of it. Without the knowledge which science alone can afford, any industry is constantly in danger of being effaced. With science as an ally it can look with confidence into the future and have an insurance, not to be obtained by other methods, against disaster.